PREDICTION OF PARAMETER VALUES FROM PHYSICAL BASIN CHARACTERISTICS FOR THE U.S. GEOLOGICAL SURVEY RAINFALL-RUNOFF MODEL

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CHAPTER I

INTRODUCTION

Objective

The development of hydrologic models allows the prediction of various hydrologic phenomena. Prediction is required for both gaged and ungaged basins. The application of hydrologic models is greatly facilitated by the use of data from gaged basins for determination of the model parameters. Subsequently, the model can be applied with various inputs, and the results analyzed. This general procedure is applied by the U. S. Geological Survey in flood frequency analysis.

Hauth (1974) describes the application of the U. S. Geological Survey Rainfall-Runoff Model[1/] in flood frequency analysis as follows:

(1) Collect rainfall and runoff data from gaged sites.

(2) Determine Model parameters by calibrating the Model with the data for gaged sites.

(3) Extend length of record for gaged site by operating the defined Model with long-term weather records of rainfall and evaporation.

(4) Determine flood frequency characteristics for each gaged site.

(5) Determine relationship between flood frequency character-

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[1/] The term "Model" refers to the U. S. Geological Survey Rainfall-Runoff Model throughout this dissertation istics and basin characteristics to allow prediction of flood frequencies at ungaged sites.

This approach to prediction at ungaged basins does not allow for the use of the Model at the ungaged site as the Model parameters are determined endogenously to the observed data at the gaged basin.

Thus, while a flood frequency relationship may be derived at the ungaged basin, the application of the Model directly to the ungaged basin for additional information is not plausible. Only through the determination of the Model parameters exogenous to observed data can the Model be applied at ungaged sites. This could be approached by relating the Model parameters determined from the gaged sites to measureable physical characteristics of the basin. The development of such a relation would allow the direct prediction of flood frequency with the Model and the prediction of the effects due to changes in the basin at the ungaged site.

The development and testing of equations for parameter prediction is the objective of the research reported herein. Two types of data were needed for this study. First, the values for the Model parameters were needed. The sources for these parameter values were previous applications of the Model to gaged sites. Second, the values for the selected physical basin characteristics were needed for each basin whose Model parameter values were available. This study determined the suitability of the available parameter values and determined the basin characteristics deemed necessary to accomplish the objective.

Hydrologic Modeling

Prior to explaining the approach followed and describing the contents of this dissertation, a basis is explored for comparing hydrologic models. The similarity between the Model used with other hydrologic models is important in order that previous studies involving other hydrologic models may be evaluated with regard to their influence on this study. By emphasizing the type of hydrologic models of concern, the following review of hydrologic modeling defines these similarities.

The composition of the hydrologic cycle as a grouping of complex, interrelated natural phenomena has lead those who study the complete cycle or any of its many facets to rely not only on the interpretation of basic data but also on the use of models. While there are a multiplicity of classifications for models, the hydrologist has tended to use models of the following three classes (Clarke, 1973):

(a) Physical - An actual replica of the prototype which is dimensioned by applying the laws of similitude.

(b) Analog - A representation of the prototype behavior patterns by applying electrical circuitry theory to analogous theoretical explanations of hydrologic phenomena.

(c) Mathematical - The use of mathematical equations and logic to either represent prototype structure and subsequent behavior or reproduce prototype behavior with no regard to prototype form.

This review is confined to mathematical models, since it is this class of models that hydrologists have placed a major portion of their emphasis over the last fifteen years.

Mathematical models also have been categorized under numerous headings. The simplest of these is the following:

(a) "Black box" - Model input is converted to output without concern for physical process(es).

(b) Conceptual - Model input is converted to output by attempting to mathematically describe the actions of the physical process(es) which determine results.

These classes may also be subdivided into categories such as stochastic or deterministic, linear or nonlinear, lumped or distributed, and time variant or stationary. Both of these main classes have their proponents and each has contributed to the study of hydrologic phenomena. However, conceptual mathematical models have allowed hydrologists the opportunity to investigate the physical laws which govern the hydrologic cycle. Thus, for this review, the term hydrologic modeling is restricted to conceptual mathematical models.

Conceptual mathematical models have been applied to the study of the hydrologic cycle in two ways. First, models of an individual component of the entire cycle have been developed. Since the 1930's, these include the work of Sherman (1932), Clark (1945) and Dooge (1959) on unit hydrograph theory, and Horton (1939) and Philip (1954) on infiltration theory, as examples. Second, models have been developed of either several dependent components or the complete cycle. Folse (1929), Dawdy and O'Donnell (1965), Crawford and Linsley (1962, 1966), and Boughton (1965) are among those who have modeled the land surface phase of the hydrologic cycle.

The gap in time between the work of Folse and that of Dawdy and O'Donnell, etc., is important for it emphasizes the crucial role which computers have played in the development of conceptual mathematical models for hydrology. The computer's ability to perform computations economically and store vast amounts of data made it not only possible to link individual components together and, thus, model the land surface phase but also to solve the differential equations which describe the physical laws governing individual components. Some examples of these are:

(1) Kinematic wave theory for flow routing by Wooding (1965) and Kibler and Woolhiser (1970).

(2) Infiltration theory by Rubin (1968).

(3) Flow in ground water systems by Bredehoeft and Pinder (1970) and Trescott (1973).

The continued improvement in computers and understanding of the individual components may eventually lead to operational models of the complete hydrologic cycle as described by theoretical sound principles in the form of differential equations. However, at this time, the description of the land surface phase as supplied by the models of Dawdy and O'Donnell (1965), Crawford and Linsley (1962, 1966) and Boughton (1965) remain the basis for many of the applications of conceptual models by hydrologists.

Thus, it is the conceptual mathematical model of the land surface phase with which this research is concerned. While the actual model used is a version of that used by Dawdy and O'Donnell (1965), it is left to later sections to describe the model and analogous experiences with the Stanford Watershed Model (Crawford and Linsley, 1966), Boughton (1965) and others. However, it is of interest to note some general similarities between them with regard to classification, structure, input and parameter value determination so that these other similar conceptual models may be compared to this Model.

Each of these conceptual models may be classified as nonlinear, lumped parametric and stationary with respect to their structure. They are nonlinear in the sense that output is not only a function of input but also antecedent moisture conditions and discontinuities created by bounded finite storages. The terms "lumped parametric" are required as conceptual rainfall-runoff models are examples of parametric hydrology[2/] and the resulting parameters are lumped with respect to space as there is no spatial variability accounted for in parameter values (except to the extent that some point values are converted to distributed basin values, e.g., infiltration in Stanford Model and USGS Model, and evapotranspiration in Stanford Model).

[2/] "Parametric hydrology is that field of mathematical hydrology which attempts to synthesize a model of land phase of the hydrologic cycle, by approximating the physical laws governing the various components of the rainfall-runoff system. Infiltration, soil-moisture storage, percolation to groundwater evapotranspiration and surface- and subsurface-flow routing are modeled by sets of equations that, hopefully, give a response equivalent to the response of the component modeled. The components and all necessary interrelations among components are described by means of parameters, some of which are empirical, and some of which have a physical interpretation" from Dawdy et al. (1972), p. B2.

The models are stationary in the sense that the parameter values are not allowed to vary through time for a model application.

The structures of these conceptual models are quite similar. Each of these models has approximately the same form in terms of representing the land phase of the hydrologic cycle. Primarily, the modeling concept is a series of storages with inflows and outflows. An inflow such as rainfall increases surface storage which is depleted by evapotranspiration, and infiltration with the excess becoming runoff. Lower zone storage(s) is (are) increased by infiltration and depleted by evapotranspiration, and drainage to lower zones or stream channels. These structural similarities require similar input, which are precipitation in the form of rainfall (capabilities for modeling snow accumulation and melt have not been considered) and potential evapotranspiration demand.

The remaining similarity in the conceptual models is the methodology used in determining parameter values. This may be described as a three step process which includes (1) selection of a data base to include observed precipitation and streamflow data for a drainage basin and appropriate potential evapotranspiration data, (2) determination of optimal parameter values which best fit the simulated to the observed data (endogenous parameter values), and (3) verification of these optimal parameters. This process will be discussed in a later chapter.

The similarities between the conceptual rainfall-runoff models mentioned and others (Nash et al., 1970; Chapman, 1968; Murray, 1970) allows for the transfer of information between these models concerning not only the individual model's structure and method for optimizing parameter values but also the applications of these models. For the purposes of this study, the application of most concern is the manner in which these models have been applied to ungaged basins. This application has relied on the development of relationships between the model parameters and physical characteristics of the basin.

Research Approach

In order that the Model parameters may be related to physical characteristics of a drainage basin, two groups of questions must be answered. The first group concerns the parameters relation to Model structure. How does the parameter influence Model output? Does the parameter interact with other parameters? If so, how does this interaction affect Model output? Does the parameter and the component containing the parameter provide significant additional information to the Model to warrant its inclusion in the Model? Does the parameter value have physical significance?

The second group of questions concern the stability[3/] of optimized parameter values. Stability must be considered because these endogenously determined values must be used to derive the relationships between the parameters and basin physical characteristics. If the optimized parameter values are not stable with respect to the

[3/] In this context, "stability" refers to the condition that an optimized parameter value at a site will remain within a narrow range when determined for similar hydrologic conditions.

aforementioned three-step process for determining optimal values, then it must be concluded that any relationships also would exhibit unstable tendencies which would result in a lack of transfer of any meaningful information between the gaged site and the ungaged site. In order to study the stability of optimized parameters the three-step process for determining the optimal values needed investigation. How do random errors in the data base affect the optimal values? What range of events should the data base represent? How much data is required? Did the search technique used find the global optimum? What objective function is best to determine the optimum parameters? Were optimized values verified over periods of time not used in the data base?

In order that the questions which have been raised in these two groups might be answered, the following tools are employed within this thesis.

(a) Literature review - a search of pertinent literature to determine whether or not the reported information may be applied to this research.

(b) Sensitivity analysis - an attempt to view not only the contribution of individual parameters, but also the effects parameters have on individual events in order to aid in judging the parameter calibration.

(c) Investigation of the process to determine optimal values. This includes an analysis of calibrations performed for previous applications.

Thus, the main objective of the study reported in this dissertation is the determination of a methodology relating Model parameter values to measureable physical watershed characteristics. The developed relationships for determining exogenous parameter values must be verified to determine whether or not they are capable of predicting meaningful parameter values for the Model. The term meaningful requires that the parameters must not only be significant to the Model's operation but also the values available as the source data, i.e., the endogenously determined parameter values, must be investigated to insure that their values are acceptable. Much of the thrust of this research is to assess this acceptability.

Description of Contents

This dissertation contains an additional seven chapters. The following is a brief description of the contents.

Chapter II provides a description of the Model by explaining its structure, defining parameters, and detailing the optimization scheme used. It also features a brief review on past Model usage, and details data available for this study.

Chapter III serves as a literature review on material concerned not only with this Model but also with other pertinent conceptual models. The areas of concern are determination of optimal parameter values, analysis of parameter sensitivity and interaction, and attempts at relating model parameters to basin characteristics.

Chapter IV presents the results of sensitivity analyses for the Model parameters. Parameter sensitivity is determined as a measure of the ratio of changes in Model output to changes in the parameter. This chapter provides the basis for determining the significance of the parameters.

Chapter V presents the determination of basin characteristics available for this study. These basin characteristics are presented in three categories, those which are termed descriptive, those related to the soils coverage, and those describing climate considerations. The amount of information available to determine soils coverage was found to be the factor which limited the number of gaged sites available for consideration by this study. The definitions and procedures used in determining values are given.

Chapter VI presents the analysis of the calibrations available for this study. The calibration process is analyzed with respect to the method used to determine the calibrated parameter values, its efficiency and ability in handling parameter interaction, and the influence of data set composition. A procedure is developed as a result of this analysis to select sites appropriate for developing relationships between the Model parameters and basin characteristics.

Chapter VII presents the relationships developed between the Model parameters and the basin characteristics. The procedure followed to determine these relationships is explained, and the physical basis for forms of the relationships is examined. A procedure to apply these relationships to produce the parameter values is discussed. Also included are the tests for verification and usefulness of the developed relationships as they are examined with respect to how they compare with the endogenous scheme for determining parameter values, and what effect they have on Model use.

Chapter VIII presents a summary of the conclusions drawn from this study. Recommendations for further study are also given.

CHAPTER II

THE U. S. GEOLOGICAL SURVEY RAINFALL-RUNOFF MODEL

Introduction

The purpose of this chapter is threefold. First, the conceptual model used in this study is described with respect to its structure and parameter optimization. Second, examples of previous applications of the Model are given. Third, the study area is delineated and available data discussed.

Description of U. S. Geological Survey Rainfall-Runoff Model

The Model expresses the major components of the hydrologic cycle with mathematical and logical statements and has a form quite similar to other rainfall-runoff models such as the Stanford Watershed Model and the Boughton Model. Appendix A contains a listing of the computer program for the Model in the PL-1 language. The Model consists of four components, a soil moisture accounting component, an infiltration component, and a surface routing component for runoff from pervious areas and a simple representation of additional runoff from impervious areas (Figure 1). The Model was developed as a means to predict flood volume and peak discharge rates for small drainage basins. Restriction to small drainage areas is necessary as not only are the contributions from ground water storage assumed to be either negligible or easily estimated

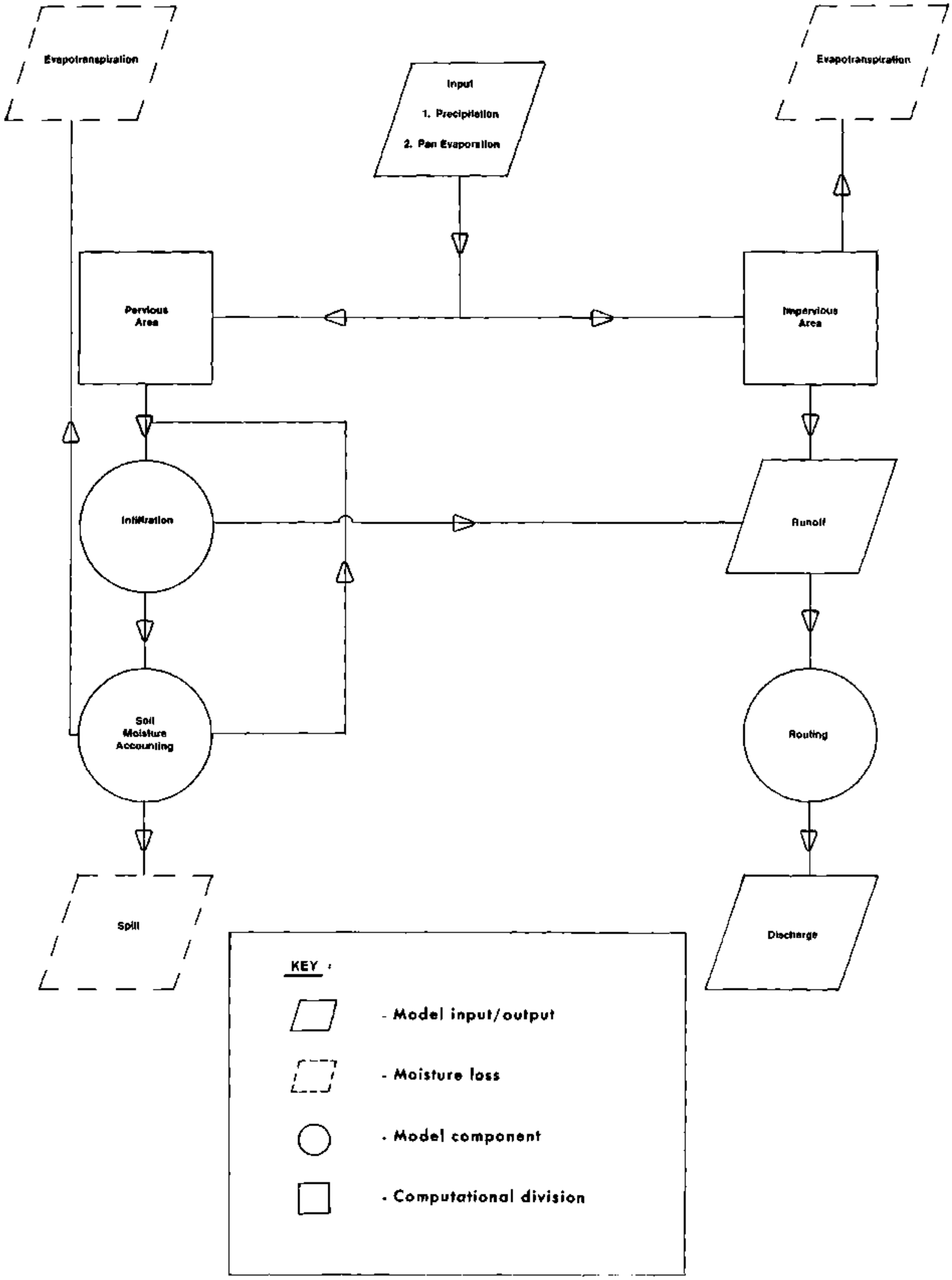

Figure 1. Generalized Flow Diagram for USGS Rainfall-Runoff Model

but also only a single raingage may be used as input. Concern with only surface runoff allows detailed computations of only rainfall events which produce surface runoff. Thus, two time intervals are used for computations. Daily time steps are used for non-surface runoff producing events, and a time interval of 5, 10, 15, 30 or 60 minutes is used for surface runoff producing events.

The Model used herein differs slightly from the versions reported previously by Dawdy and O'Donnell (1965) and Dawdy, Lichty, and Bergmann (1972). The earliest version differs in two basic areas. First, Dawdy and O'Donell attempted to model not only surface runoff but also the flow contribution from groundwater storage whereas the current version is concerned with surface runoff only. Second, the infiltration component used by Dawdy and O'Donnell is based on work by Horton (1942) while this version models infiltration by an adaptation of Philip's approach (1954). The reasoning for selection of Philip's approach is presented in a paper by Dawdy and Lichty (1968). They chose the Philip approach because it not only produced slightly better results but also it was simpler and had a more physically based interpretation. The version reported in Dawdy et al. (1972) has a variation in the routing component. The "actual" time-area curve used in the earlier report has been replaced by a triangular representation (Carrigan, 1973) requiring the calibration of two parameters.

<u>Model Structure</u>

The Model was structured to have a "degree of equivalence to the physical system" (Dawdy et al., 1972) and consists of the four mentioned components, soil moisture accounting, infiltration, surface runoff routing, and a simple representation of additional runoff from impervious areas. While the mechanism for runoff from impervious areas will be mentioned, this study is primarily concerned with rural drainage basins and, thus, detailed discussion is limited to the first three components. Three time series of observed data are required for input. These include two series of rainfall data from a single continuous[1/] rainfall gage. Daily rainfall amounts for moisture accounting purposes and unit rainfall[2/] amounts for days which have been selected as surface runoff producers. The third data series required is daily evaporation data, usually obtained from National Weather Service Class A pan evaporation data for a nearby site.

As shown in Figure 2, the soil moisture accounting portion of the Model determines the soil moisture conditions which affect the initial infiltration rates required in the calculations of rainfall excess. The rainfall excess is then routed by the surface routing component to produce storm hydrographs at the basin outlet.

1/ Within this dissertation, continuous refers not only to the continuous analog type record, but also to the descrete digital record provided at a constant time interval.

2/ Unit rainfall refers to data derived from a continuous rainfall record by determining the incremental amount which occurred during a specific time interval (5, 10, 15, 30 or 60 minutes are used with the Model).

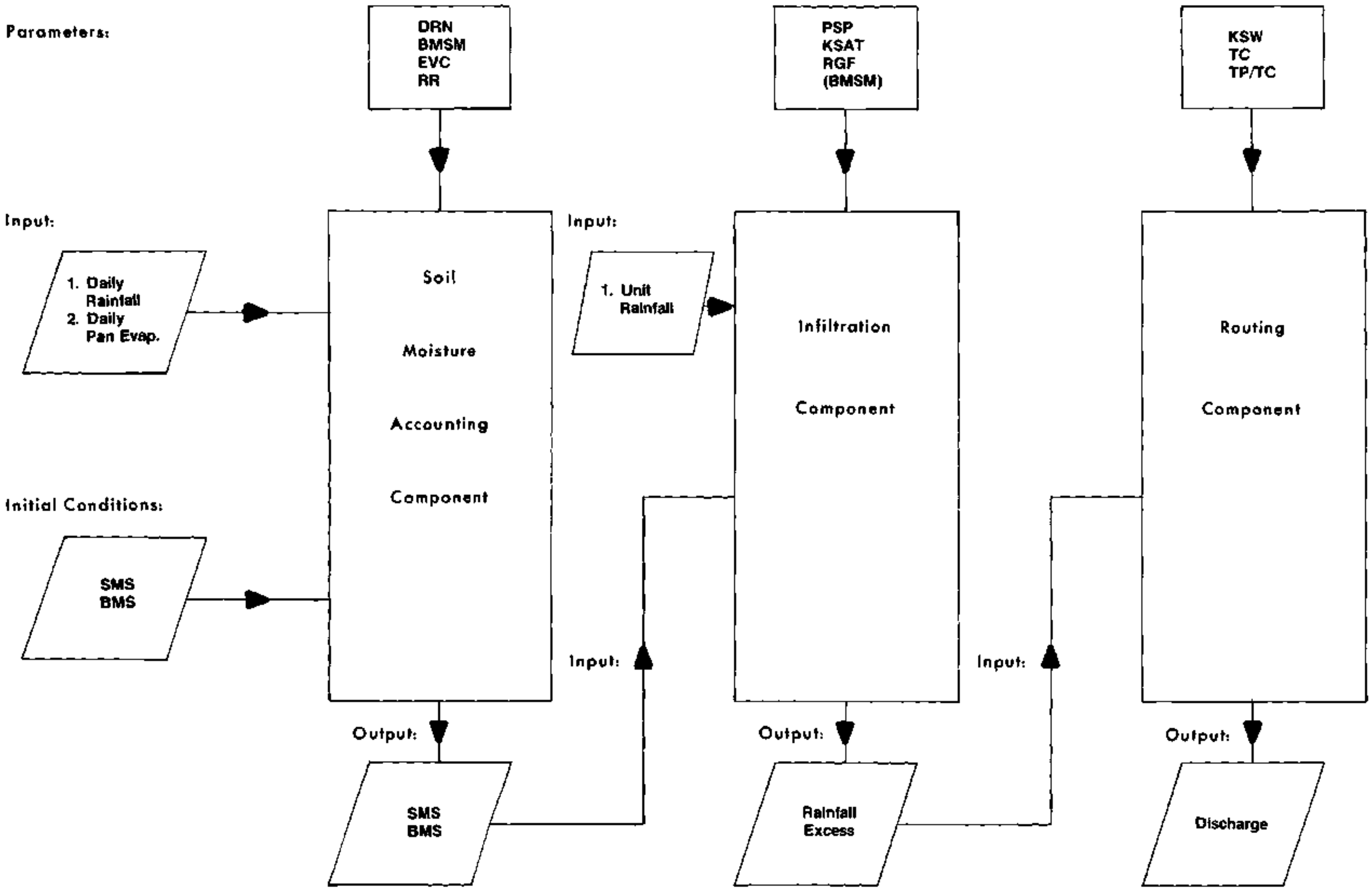

Figure 2. Flow Diagram of USGS Rainfall-Runoff Model showing relationships among components,parameters and variables

The remainder of this section will describe these components in more detail. The order of presentation follows the diagram in Figure 2.

Soil Moisture Accounting Component. This component simulates the distribution of moisture in the soil column in order that the initial infiltration rate may be determined for a storm event. The computations within this component must be compatible with the infiltration component so that a water budget of the total moisture in the soil column may be maintained. For this purpose, the soil column is divided into two storage layers. The upper layer is referred to as surface moisture storage, SMS. It accumulates all infiltration during storm periods and drains to the lower storage layer during non-storm periods. The lower storage layer is referred to as base moisture storage, BMS, which can vary from field capacity to wilting point conditions. It is used to compute the relative soil moisture deficit. The rules for maintaining these storage layers, the necessary parameters and inputs are given below.

The moisture accounting process occurs during storm and non-storm periods. The accumulation of infiltration is SMS during storm periods is explained in the discussion of the infiltration component. Moisture accounting during non-storm periods is explained here. Non-storm periods include: (A) days which are not selected as storm events and (B) periods within storm events which have no rainfall. The logic rules for operating these two storage elements are presented within the context of this definition of non-storm periods.

(A) Days which are not selected as storm events--Inputs are daily Class A pan evaporation data, DE, and initial values of SMS and BMS. The output variables are the current values of SMS and BMS. The rules of operation and explanation are as follows:

(1) BMS = BMS + SMS + DP*RR - DE*EVC. Base moisture storage, BMS, is incremented by the additions of drainage from surface moisture storage, SMS, a proportion of daily rainfall, DP*RR, and the loss due to evapotranspiration, DE*EVC.

(2) SMS = 0.0. SMS drains completely to BMS during a day time step.

(3) If BMS > BMSM then BMS = BMSM. The amount of BMS greater than BMSM is lost to the system and BMS is set equal to BMSM.

(4) If BMS < 0.0 then BMS = 0.0. The lower bound of BMS is zero storage.

The three required model parameters are defined as:

(1) RR is the fraction of daily rainfall that infiltrates the soil. It has no units.

(2) EVC is a coefficient to convert pan evaporation to potential evapotranspiration values as evapotranspiration losses are assumed to occur at the potential rate if sufficient moisture is available in BMS. It has no units.

(3) BMSM is the maximum value for BMS. This is the soil moisture volume at field capacity. It has units of inches (centimeters).

In addition to computed surface runoff and evapotranspiration, the rules of operation cause moisture loss from the model by daily precipitation that does not infiltrate, (1-RR)*DP, and spill to deeper storage when BMS exceeds BMSM. SMS is considered to drain completely to BMS during the days where surface runoff is not computed.

(B) Periods within storm events which have no rainfall-- Inputs are daily pan evaporation data expressed as mean value per unit time interval, DE*PDEL, where PDEL is unit time intervals per day, and initial values of SMS and BMS. The output variables are the current values of SMS and BMS. The rules of operation and explanation are as follows:

(1) DRNPER = DRN * KSAT. The amount of drainage which will occur from SMS to BMS in a period is defined as a fraction of the saturated hydraulic conductivity.

(2) ETDEL = EVC * DE * PDEL. ETDEL is the incremental value of evapotranspiration that occurs during a day. For storm events, it is assumed to affect storages only during periods with no rainfall.

(3) If SMS - ETDEL < 0.0 then the following occurs (a) BMS = BMS + SMS - ETDEL, (b) SMS = 0.0, and (c) if BMS < 0.0 then BMS = 0.0. This allows for the condition when the amount of incremental evapotranspiration is greater than the amount of storage in SMS. It then follows that BMS is decremented but not below its lower bound,

and SMS is set to zero.

(4) If SMS - ETDEL $\geq$ 0.0 then SMS = SMS - ETDEL. This allows for the condition when the amount of incremental evapotranspiration is less than or equal to the amount of storage in SMS. In this case, these losses are met from SMS.

(5) If SMS > DRNPER then the following occurs (a) SMS = SMS - DRNPER, and (b) BMS = BMS + DRNPER. If the value of storage in SMS is greater than the amount which can drain in this time period, then SMS is decreased by this amount and BMS is correspondingly increased.

(6) If SMS $\leq$ DRNPER then the following occurs (a) BMS = BMS + SMS, and (b) SMS = 0.0. When the amount of drainage is greater than the moisture available, all the moisture drains to BMS and SMS becomes zero.

(7) If BMS > BMSM then BMS = BMSM. The amount of BMS greater than BMSM is lost to the system and BMS is set equal to BMSM.

The three required parameters are:

(1) KSAT is the value of saturated hydraulic conductivity used to determine infiltration rates. It is explained further in the next section and has units of inches per hour (cms per hour).

(2) DRN represents a constant fraction for redistributing moisture from surface moisture storage to base moisture storage. It is inputted as a fraction of KSAT. It has no units.

(3) EVC is defined above. The rule for ETDEL shows that evapotranspiration losses are assumed to occur at a uniform rate during the entire day.

(4) BMSM is defined above. The rules of operation show that moisture lost from the model is the amount that BMS exceeds BMSM, and SMS drains to BMS at rate not to exceed DRNPER during periods of no rainfall.

Thus the soil moisture accounting component serves to continually update the values of SMS and BMS so that the infiltration component is based on the current antecedent conditions.

Infiltration Component. This component computes the rainfall excess available for routing to the basin outlet by deducting an infiltration amount from the precipitation. The infiltration of the water into soil is estimated from Darcy's law for flow through a porous media and an approximation to the pertinent differential equations by Philip, 1954. The pertinent theory and parameters are presented first, then the operating rules for this component are discussed.

Philip assumed a two-layered structure for the soil column. His approach may be summarized as follows (see Figure 3):

> Initially, the soil column has a uniform soil-moisture content, m_o, expressed as a proportion of total volume. This represents antecedent moisture and the amount is shown in Figure 3 as the unhachured area. As rainfall strikes the surface, a wetter layer of soil forms. This

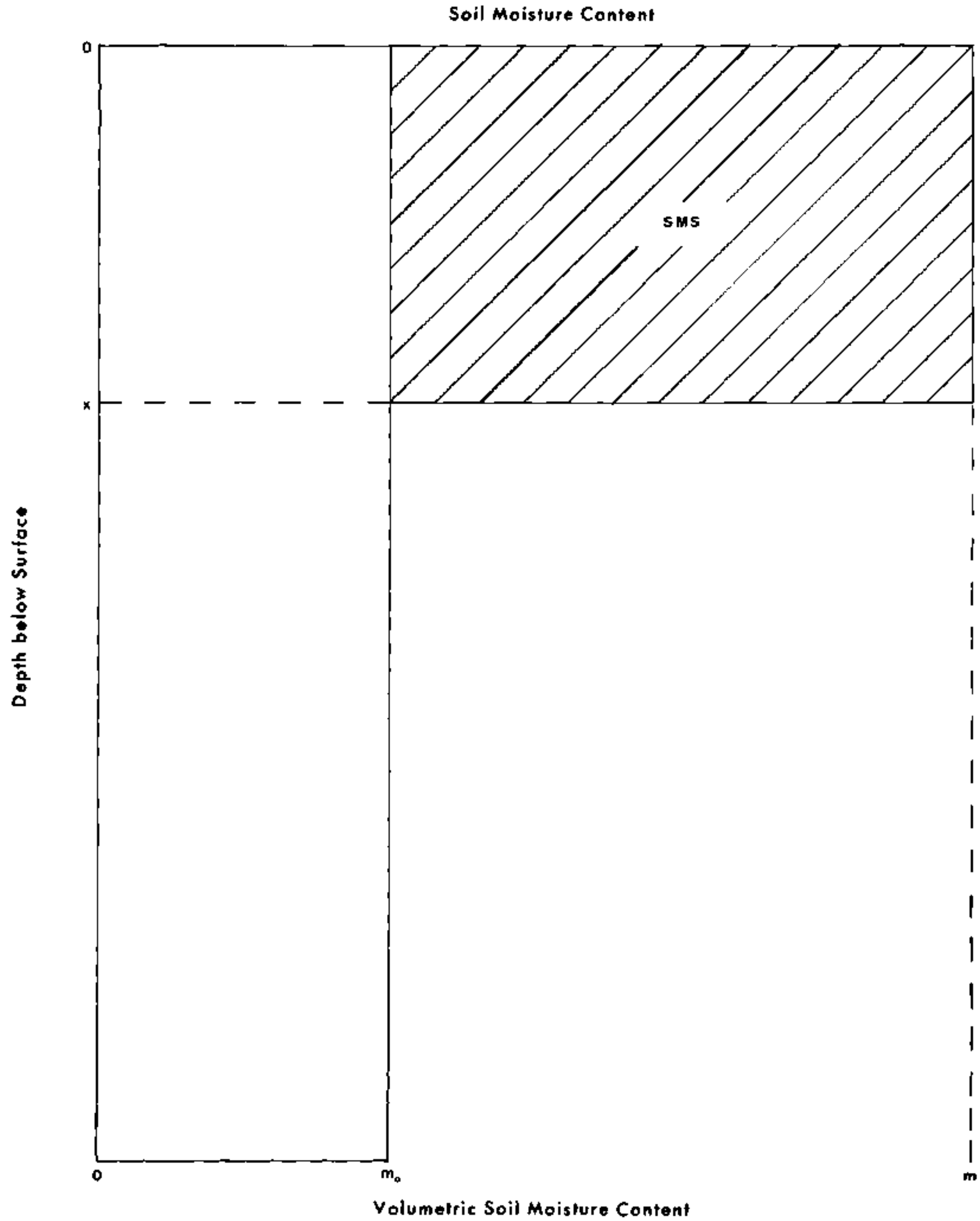

Figure 3. Schematic Diagram of the two-layered soil moisture profile used with the Infiltration Component (Dawdy et. al.,1972)

upper layer attains a uniform moisture content, m, which approaches saturation for the layer, and extends from the surface to a depth, x. This layer is assumed to have a constant velocity of flow downward through the remainder of the soil column. It may be thought of as a transmission zone in which the average hydraulic conductivity will remain constant as well as the average moisture content. If the depth, x, is considered to define the depth of the wetting front then this layer also contains a wetting zone which varies in moisture content. The moisture content of the lower layer, m_o, will be incremented as the capillary potential of the unsaturated lower layer draws moisture from the wetter upper layer, $m > m_o$. The amount of infiltrated moisture, $(m - m_o)*x$, is shown as the hachured area of Figure 3.

These assumptions lead to the following form of Darcy's law.

$$\frac{V*x}{k} = P + x + h$$

or

$$V = k*[1 + \frac{P + H}{x}] \qquad \text{(II.1)}$$

Where V is downward velocity of flow;

k is value of hydraulic conductivity for the saturated transmission zone;

P is capillary potential at the wetting front;

H is depth of ponded water at surface;

and

x is depth below surface to wetting front.

Compared to the capillary potential, H is negligible, and using

$$V = \frac{di}{dt} \tag{II.2}$$

and

$$i = x * (m - m_o), \tag{II.3}$$

where i is the accumulated infiltration in the wetting layer, equation (II.1) becomes

$$\frac{di}{dt} = k * [1 + \frac{P(m - m_o)}{i}] \tag{II.4}$$

Equation (II.4) is the basis for computation of the infiltration rate in the model. Writing this equation with identifiers used by the USGS computer program yields infiltration rate,

$$FR = KSAT\ [1 + \frac{PS}{SMS}] \tag{II.5}$$

The variables in this equation are:

(1) PS is the effective capillary potential and is defined in equation (II.6) below.

(2) SMS is the current value of accumulated infiltration.

The one parameter shown in equation II.5 is:

(1) KSAT is the value of saturated hydraulic conductivity

used to determine infiltration rates. It occurs in the transmission zone and has units of inches per hour (cms per hour)

Dawdy, Lichty and Bergmann contend that capillary potential at the wetting front, PS, is not a constant, but varies with initial moisture condition (Lichty et al., 1968; Dawdy et al., 1972). This is supported by an implication from Colman and Bodman, 1944 (a reference used by Philip) that initial moisture content strongly influences suction between wet and dry soils.[3/] Philip also lends credence to this view from his expression for effective capillary potential, $P(m - m_o)$, which does show a dependence on the initial moisture conditions as given by m_o. As neither Colman and Bodman or Philip suggested a procedure to show this variation, Dawdy, Lichty and Bergmann assumed a linear relationship for effective capillary potential, PS (Figure 4). This relationship results in the following equation:

$$PS = PSP\ [RGF - (RGF - 1)\ \frac{BMS}{BMSM}] \qquad (II.6)$$

The one variable in this equation is:

(1) BMS is the current value for base moisture storage. It serves as the measure of antecedent moisture in the

[3/] "Of the changed conditions brought about by using moist rather than air-dry soils, the observed results indicate the particular importance of the lowered potential gradient at the wet front. This lowered potential gradient dominates the infiltration process in the experiments with moist soil, and reduces the rate of entry," Colman and Bodman (1944), p. 5.

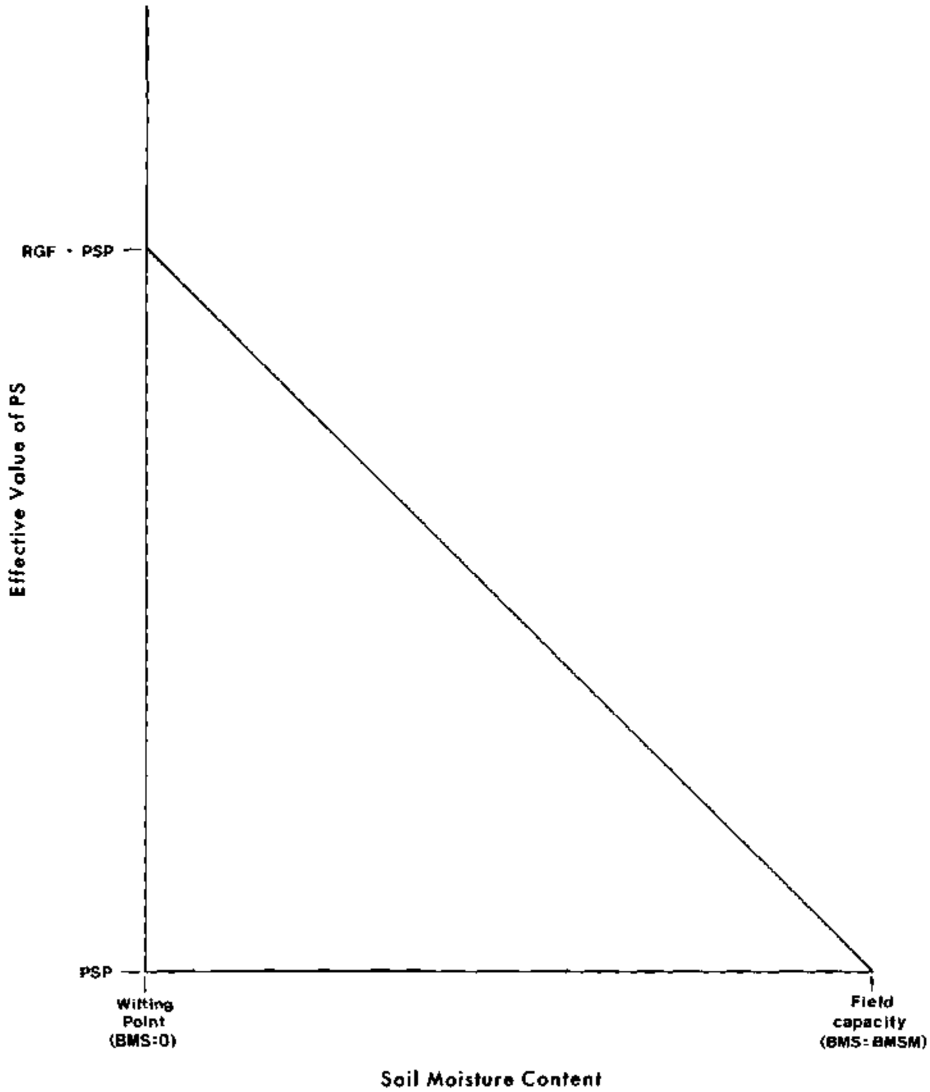

Figure 4. The Relation which determines the Effective Value of Soil Moisture Potential,PS (Dawdy et. al.,1972)

soil column.

The three parameters in this equation are:

(1) PSP[4/] is the minimum value of the effect of capillary suction and the soil moisture differential at the boundary between the two layers of the soil column. This value occurs when lower layer moisture content is at field capacity, BMS = BMSM. PSP is in inches (centimeters).

(2) RGF is a range factor, which is the ratio of PSP at wilting point conditions, BMS = 0, to that at field capacity, BMS = BMSM. Thus, RGF * PSP is the maximum value of the effect of capillary suction and the soil moisture differential at the boundary between the two layers of the soil and RGF * PSP occurs when BMS = 0. RGF has no units.

(3) BMSM is defined in the discussion on the soil moisture accounting component.

Two points need to be emphasized with respect to equations (II.5) and (II.6). First, they show the direct link between this component and the moisture accounting component due to the prominence of variables SMS and BMS, and the reappearance of the parameter BMSM. Second, they produce the infiltration rate at a point in the basin.

[4/] Referred to as SWF in Dawdy et al., 1972.

As point infiltration rates will vary over the basin, two assumptions were made so that basin infiltration could be computed. First, equations (II.5) and (II.6) yielded an FR which was maximum for the entire basin. Second, the cumulative frequency distribution for infiltration capacity (Figure 5) was assumed to vary linearly from zero to the maximum, FR.[5/] This distribution was then used to compute the rate of precipitation excess, QR, from the supply rate of rainfall for infiltration, SR, by deriving the following equations from Figure 5:

$$QR = SR^2 / 2 * FR \text{ for } SR < FR \qquad (II.7a)$$

and

$$QR = SR - (FR/2) \text{ for } SR \geq FR \qquad (II.7b)$$

Thus, equations (II.5), (II.6) and (II.7) form the basis for the infiltration component for computation of rainfall excess. This component operates only during storm periods. Storm periods are defined as time periods within storm events which have rainfall. Inputs into this component are the current values of SMS and BMS and the supply rate of rainfall during the period, SR. Outputs produced are the updated value of SMS and FR and the amount of rainfall excess, QR. Evapotranspiration losses are ignored during the time period. The logic rules for operation this component and

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[5/] A concept adapted from Crawford and Linsley, 1966, pp. 31-32.

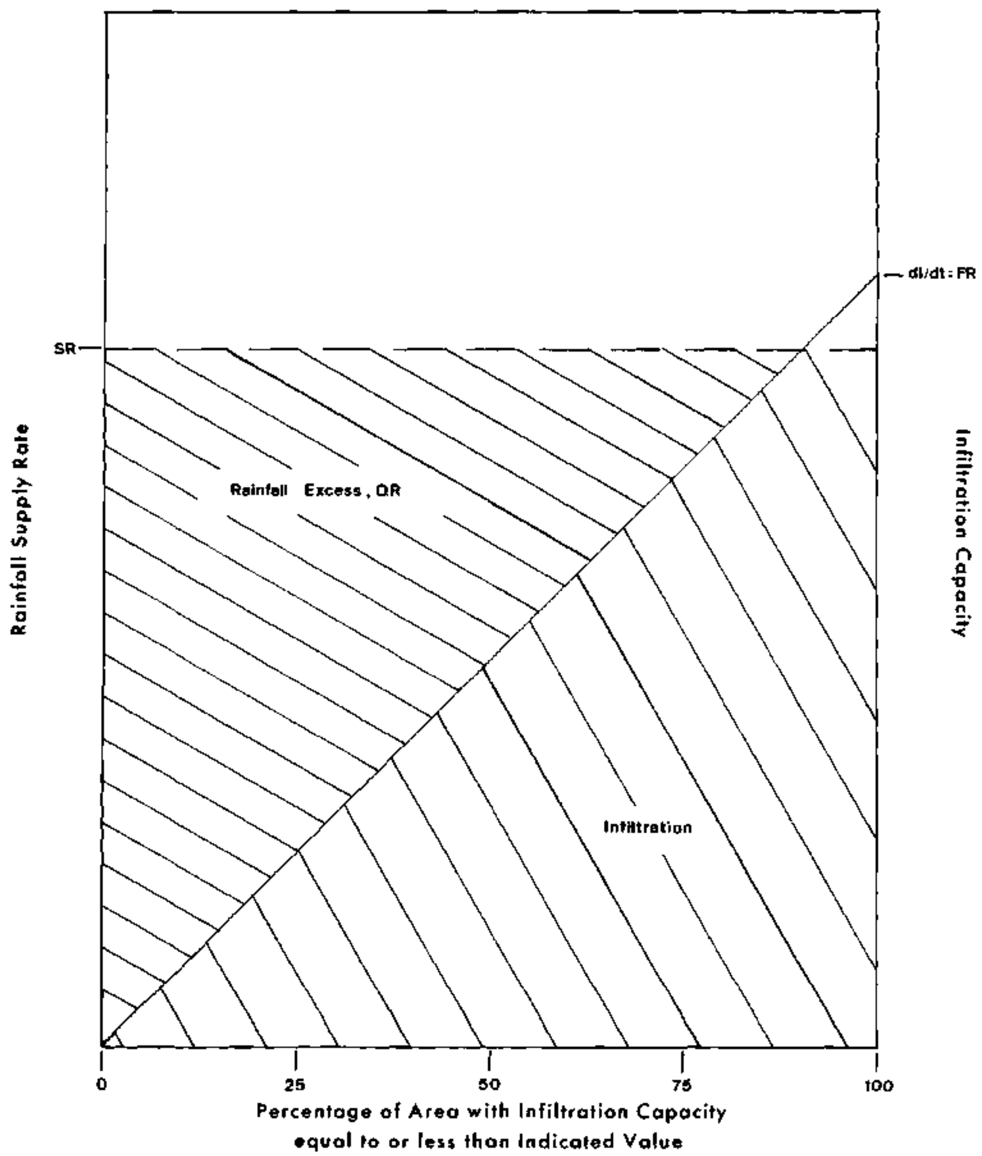

Figure 5. The Relation which determines Rainfall Excess, QR, as a function of Maximum Infiltration Capacity, FR, and Supply Rate of Rainfall, SR (Dawdy et. al., 1972)

explanations are as follows:

(1) If SMS = 0.0 then the following occurs (a) PS is set using equation (II.6) and (b) FR is computed from equation (II.5) considering the supply rate of rainfall, SR, as the value for SMS. The effective capillary potential is recomputed when SMS = 0.0 due to changes caused by incrementation to BMS. SMS will equal zero at the start of a storm event and after sufficient losses and drainage have depleted it during non-rainfall periods of the storm event. The infiltration amount, FR, for this period is based on the amount of rainfall available to SMS, SR.

(2) If SMS > 0.0 then FR is set according to equation (II.5). The infiltration amount is controlled by the moisture stored in SMS.

(3) If SR < FR then QR is determined from equation (II.7a). If the supply rate of rainfall is less than the expected infiltration amount, the precipitation excess, QR, is computed from equation (II.7a).

(4) If SR $\geq$ FR then QR is determined from equation (II.7b). If the supply rate of rainfall is greater than or equal to the expected infiltration amount, the precipitation excess is computed from equation (II.7b).

(5) SMS = SMS + SR - QR. SMS is adjusted by an increase due to the supply rate of rainfall, SR, and a decrease from

the runoff of precipitation excess, QR.

Thus, the infiltration component applies equations (II.5), (II.6), (II.7a) and (II.7b) and the current values of SMS and BMS to produce the precipitation excess from pervious areas. For the majority of applications, this has represented the total amount of runoff produced. However, basins with impervious areas have also been modeled.

Precipitation excess from impervious areas is computed by assuming a maximum retention of moisture on the impervious surface equal to 0.05 inches (0.127 cms). Once, this amount of storage is full, the remaining rainfall less evapotranspiration losses becomes precipitation excess from the impervious area. Evapotranspiration losses are computed as described by the soil moisture accounting component for the non-storm periods. Only precipitation excess computed for storm periods is accounted for by the model, and it is added to excess from pervious areas so that the total precipitation excess serves as input to the routing component.

Surface Routing Component. This component transforms the total precipitation excess into a discharge hydrograph at the basin outlet. The method used to accomplish this transformation is adapted from Clark (1945) and comprises two steps, translation by use of a triangular translation hydrograph[6/] and attenuation by linear

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[6/] "A Linearized abstraction of a hydrograph based on the variation of area, in concentric bands which are everywhere equidistant from the outlet, with the travel times from the bands to the basin outlet." Carrigan, 1973.

storage. Prior to discussing the operating rules and introducing the parameters used in this component, Clark's method is outlined.

Clark's method (Figure 6) requires development of a time-area histogram for a basin. This would encompass computation of travel times to all points of the basin. Since this would require a major effort, a simplification was introduced by drawing concentric circles through assumed equal travel times to the outlet. The plot of area between these concentric circles versus travel time is the time-area histogram. By assuming that 1 inch of precipitation excess occurs instantaneously and uniformly over the basin, a time-discharge histogram, i.e., a translation hydrograph, is developed. After development of this translation hydrograph, Clark then routed it through time-invariant linear storage where storage is the product of a constant time coefficient and outflow (equation II.9), and produced the instantaneous unit hydrograph at the basin outlet.

Previously this method was applied without modification in the Model. However, to remove the influence due to selecting faulty travel times, the Model was modified by replacing the time-area histogram with a triangular representation.

The operation of the routing component may be stated as using the triangular translation hydrograph to determine inflow to the linear storage reservoir by convoluting the ordinates of the translation hydrograph with the total precipitation excess. This operating procedure and the necessary parameters are expressed in the following equations:

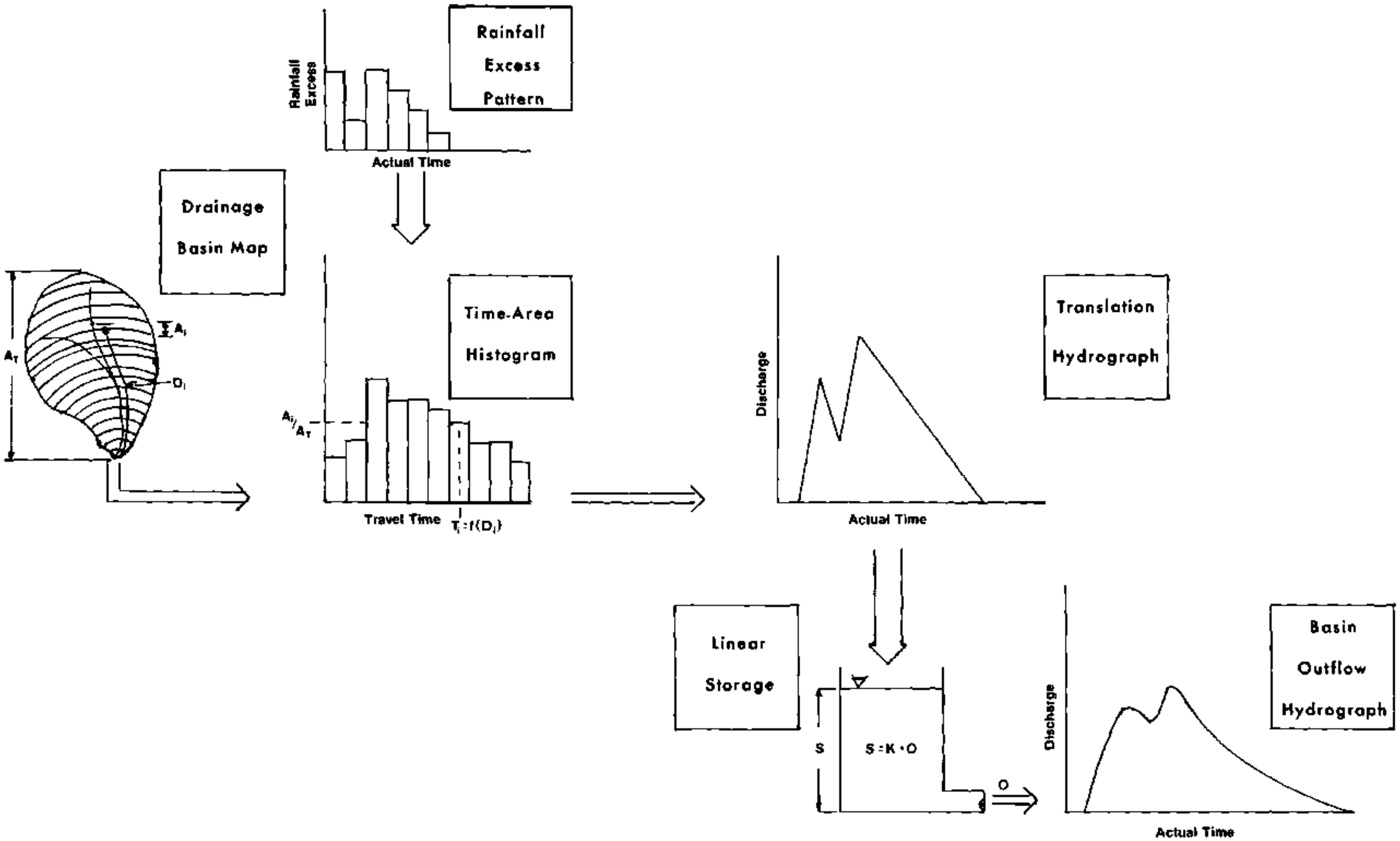

Figure 6. Schematic of the Clark Flood Routing Method

$$QI(t) = \sum_{i=1}^{n} (TA(i) * QR(t - i + 1)) \qquad (II.8)$$

where t is defined as ranging from 0 to T, the end of the storm event;

QI(t) is the ordinate of the inflow hydrograph to linear storage at time t;

TA(i) is the ordinate of the triangular translation hydrograph at time i where TC, the base, has been divided into n equally spaced intervals; TP gives the location for the peak of the triangular translation hydrograph (Figure 7).

and QR (t - i + 1) is the rainfall excess value computed in the infiltration component for each time equal to and subsequent to t by n * Δt.

This inflow is then routed through linear storage with a constant time characteristic, KSW, which may be expressed as

$$S(t) = KWS * QO(t) \qquad (II.9)$$

where S(t) is the amount of storage at time t; and

QO(t) is the outflow at time t.

Noting that the rate of change in storage is equal to the difference between the inflow and outflow rates yields

$$QI(t) - QO(t) = KSW[\frac{d(QO(t))}{dt}] \qquad (II.10)$$

Considering QI(t) constant for the time interval, Δt, and rearranging

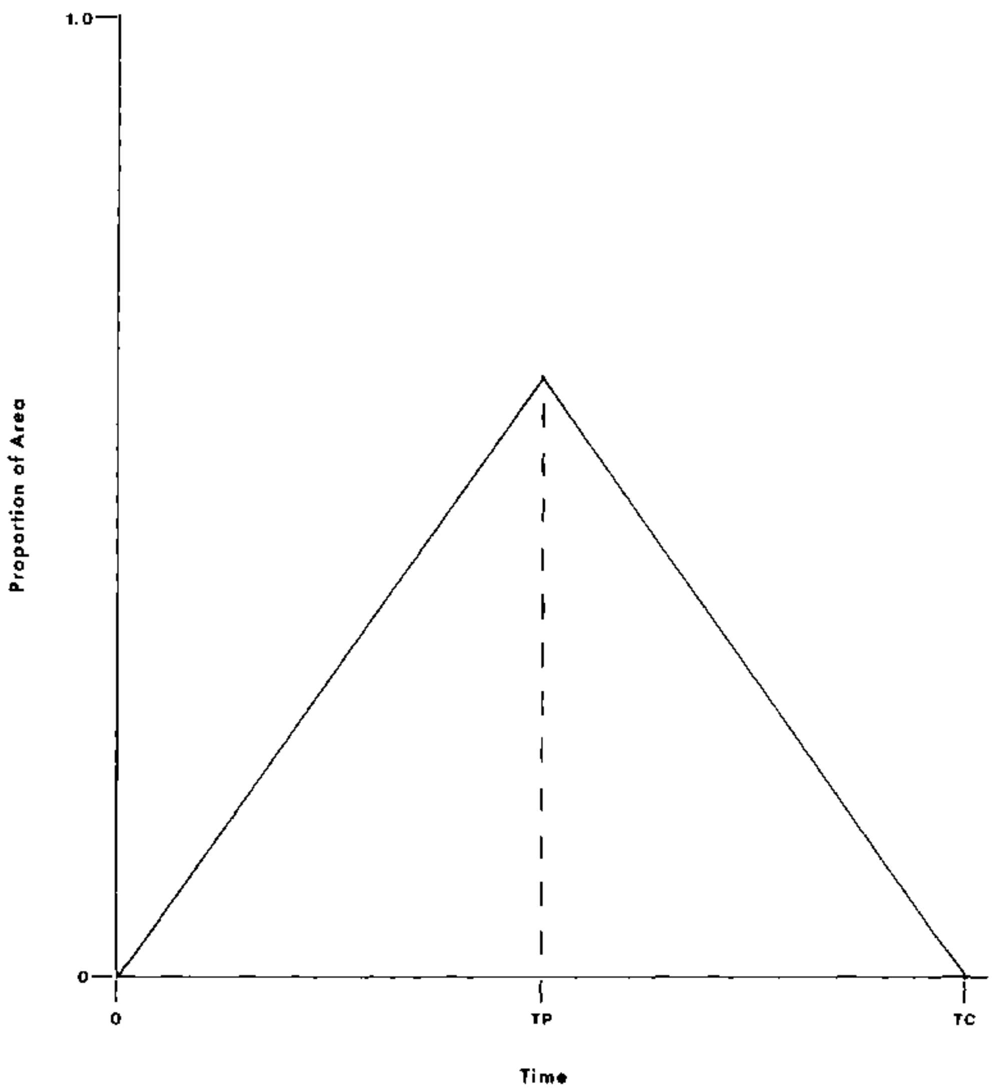

Figure 7. Triangular Translation Hydrograph

with Unit Area (Carrigan,1973)

terms, equation (II.10) becomes

$$\frac{d(QO(t))}{dt} + \frac{1}{KSW} * QO(t) = \frac{1}{KSW} * QI. \qquad \text{(II.11)}$$

Solving equation (II.11) from t to $(t + \Delta t)$ by use of the integration factor $e^{t/KSW}$ yields

$$QO(t + \Delta t) = QI - (QI - QO(t))e^{-\Delta t/KSW} \qquad \text{(II.12)}$$

The solution of equation (II.12) determines the output for this component, the discharge hydrograph at the basin outlet.[7/] The three required parameters are:

(1) KSW is the constant time coefficient for the linear reservoir routing. KSW has units of hour.

(2) TC is the duration of the triangular translation hydrograph. It represents the time of concentration.[8/] TC has units of minutes.

(3) TP/TC is the ratio of the time to the peak of the triangular translation hydrograph to its duration, the time of concentration. TP/TC has no units.

[7/] When inflow ceases, i.e., QI = 0, then, equation (II.12) becomes

$$QO(t + \Delta t) = QO(t) * e - \Delta t/KSW$$

[8/] Time required for surface runoff from the most remote part of the basin to reach outlet. (Chow, 1964).

Thus, the routing component applies equation (II.8) and (II.12) to determine the discharge hydrograph at the basin outlet.

Model Operation Summary

A brief summary of the Model operation follows:

(1) Daily rainfall and pan evaporation data are used in the soil moisture accounting component to determine antecedent soil conditions, i.e., values of BMS and SMS.

(2) During storm events when unit rainfall values are greater than zero:

  (a) The values of SMS and BMS are used in equations (II.5) and (II.6) to determine maximum point infiltration for the basin.

  (b) Equations (II.7a) and (II.7b) are used to determine the net amount of infiltration over the basin, and, thus, compute rainfall excess QR, from pervious areas.

  (c) Rainfall excess from impervious areas is computed.

(3) During storm events when unit rainfall values equal zero then the values of SMS and BMS are affected by the same moisture accounting procedures used in step (1).

(4) The array of rainfall excess values is then transformed into a triangular translation hydrograph.

(5) The discharge hydrograph at the basin outlet is computed from equation (II.12) for the storm event.

(6) Upon ending the storm event, Model control reverts to step (1) unless there is no more storm data in which case Model operation ceases.

Optimization Process for Determining Parameter Values

As mentioned in Chapter One, the methodology used in determining parameter values consists of three steps, (1) selection of a data base, (2) determination of the optimal parameter values, and (3) verification of these optimal parameter values. The parameters are determined by fitting model output to observed data, which gives endogenous parameter values. Such a method must be concerned with (a) random data errors which will influence parameters, (b) parameter interdependence and (c) model adequacy. This section is intended to illustrate the manner in which this three-step process has been applied to the Model with particular emphasis on step 2.

(1) Selection of Data Base. This step consists of the following: (a) selection of a site with rainfall and streamflow data, (b) review of observed data to check the quality of records, (c) selection of storm events to be used for calibration and (d) selection of a suitable pan evaporation station. For the most part, items (a) and (b) tend to complement themselves. For example, the USGS has set up small streams gaging networks in order to determine flow characteristics from smaller drainage areas by gaging discharge and rainfall at the basin outlet. If the collected data is of good quality, i.e., stable stage-discharge ratings and compatible rainfall/runoff records, then the gage is suitable for Model calibration.

Item (c) may be handled in several ways including one of the following: (i) Select range of events from low to high flow; (ii) Select events based on discharge exceeding a minimum value; (iii) Select events based on a threshold daily rainfall total (even though runoff may indicate rainfall did not cover basin). Each of these will effect the parameter values estimated by Model calibration. Assuming a good fit, approach (i) will yield parameters which should reproduce the range of hydrologic events while (ii) would give a parameter set that reproduces the higher discharge events, and (iii) would give a parameter set attempting to smooth the effects of areal variations in rainfall. Primarily approaches (i) and (ii) have been used with this Model. Events indicating rainfall did not cover basin have invariably been part of data samples under approach (i). Item (d) has been accomplished by choosing a pan evaporation data site near the basin of concern, and assuming that pan evaporation data represents average basin conditions.

(2) Determination of Optimal Parameter Values. This step requires (a) criteria to judge best fit and (b) a technique to adjust the parameters so that the best fit criteria will be satisfied. The choices to fulfill these requirements will affect parameter results due to scaling effects, search efficiencies, and model and data adequacy.

For the Model, the criteria of best fit to an objective function was chosen to insure that the Model reproduced storm runoff volumes and peaks. This is a logical choice, since the Model was developed to predict peak flows and volumes from small drainage basins. The form chosen was to minimize the sum of squares of the difference between the transformed observed and computed outputs. As Dawdy, Lichty, and Bergmann observed, this is appealing for an objective function in the form of a sum of squared errors has not only the mathematical property of convexity[9/] but also the analogy to least squares fitting in statistics. A logarithmic transformation was used to weight the error of estimation relative to the size of the output. Thus, small errors on large peaks would not affect the objective function value as much as large errors on small peaks. Chapter VI discusses various forms for the objective function and their influences on determining the error estimation. The actual forms of the objective functions used are as follows:

$$OF_1 = \text{Minimize} \sum_{1}^{\#FE} [\text{LOG } (V_c) - \text{LOG } (V_o)]^2, \qquad \text{(II.13)}$$

[9/] A function, y, is said to be convex if it is never over estimated by a linear interpolation between any two points, x_1, and x_2. Thus, for "a" in the range 0 to 1.0, y would be convex if

$$y(ax_1 + (1 - a)x_2) \leq ay\ (x_1) + (1 - a)y\ (x_2).$$

Strict convexity is defined by replacing $\leq$ with $<$.

A feasible region, F, such as defined by constrained parameter values, is said to be convex if a straight line between any two points, x_1 and x_2, which are members of the set of all points composing F, lies entirely within F.

The importance of this concept lies in the fact that if y is strictly convex in a region, F, then y is unimodal and the local minimum is the global minimum. (Wilde and Beightler, 1967).

$$OF_2 = \text{Minimize} \sum_{1}^{\#FE} [\text{LOG}\ (P_c * \frac{V_o}{V_c}) - \text{LOG}\ (P_o)]^2 \quad \text{(II.14)}$$

and

$$OF_3 = \text{Minimize} \sum_{1}^{\#FE} [\text{LOG}\ (P_c) - \text{LOG}\ (P_o)]^2, \quad \text{(II.15)}$$

where V refers to storm event volume, in inches

P refers to storm event peaks, in cfs,

c, the subscript, means computed by Model

o, the subscript, means observed data,

and #FE is the total number of storm events.

Prior to elaborating on the calibration procedure, the actual technique needs to be introduced.

The technique used to determine the parameter set which would give the minimum value for each of these three objective functions is that introduced by Rosenbrock (1960) to find the greatest or least value of a function in which (a) the parameters are constrained and (b) the partial derivative with respect to the parameters are not capable of being solved analytically. Both (a) and (b) are common to any conceptual hydrologic model as parameters must be limited to physically realistic values in order that a parameter is not entirely a "curve-fitter" and the mathematical discontinuities and logical statements required in a rainfall-runoff model make it improbable that a set of meaningful equations for the partial derivatives could be determined. Rosenbrock's technique has been used in fitting several hydrologic models (Dawdy and O'Donnell, 1965; Ibbitt, 1970; Smith, 1971; Leavesley, 1973).

In general, the Rosenbrock technique, the method of rotating coordinates (Wilde, 1964), optimizes the n-parameters (x_1, x_2, --x_n) defining the objective function, OF, by considering an (n + 1) dimensional hyperspace formed by the set of all possible points (x_1, x_2, ---, x_n; OF). the hyperspace is formed by the n orthogonal parameter axes and bound by the constrained parameter values. The technique then searches this hyperspace until the optimum value of OF is found. The search is termed recursive as it proceeds by a series of repetitive stages. Each stage consists of a search along each of the n orthogonal axes by performing a series of singular steps taken along each successive orthogonal axis. This means that a second step is not taken along a parameter axis until all other axes have had their first step, and thus, a series of parallel rather than colinear steps result.[10/] An initial value of OF is computed to serve as a base by using starting parameter values which are within the constraints. Following the computation of the base OF, the starting parameter values are incremented by an initial step. The initial step length is of arbitrary length, and subsequent step lengths depend on whether or not the value computed for OF is an improvement. If OF improves, then the step is a success and the step length is increased by a factor greater than 1.0. If OF does not improve, the step is a failure and not only is it

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10/ Ibbitt (1970) contends that "by creating the opportunity for searching directions parallel to the unprofitable direction, one step at a time, an increase in both search economy and effectiveness should result." (p. 120).

not allowed but also the step is repeated (i.e., the step counter is not incremented) with a step length adjusted by multiplying with a factor within the range -1.0 to 0. A stage is terminated once the end of stage criteria, i.e., a success followed by a failure is achieved for each of n parameters, is met. The orthogonal axes then rotated so that one axis points in the direction of fastest advance as determined by the just terminated stage. The other axes are arranged normal to this one. This is accomplished by the Gram-Schmidt orthonormalization process. The starting point for this next stage is the set of parameter values for the last successful reduction of OF. This process continues until either a convergence criteria is met or a selected number of total attempts at adjusting the parameters is exceeded.

Prior to applying this technique, the USGS made several modifications (Carrigan, 1972). Appendix B contains a listing of the PL-1 computer program for the modified version of the Rosenbrock technique. The modifications made are (1) end of stage criteria, (2) determining number of steps and (3) convergence criteria. They are explained as follows: (1) End of stage criteria - A stage is ended and a new orthonormal basis derived when all attempts to change each of n-parameters has resulted in a failure. In effect, this allows a greater portion of the hyperspace to be searched before orthonormalization.[11/] (2) Determining number of steps - Each

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11/ Ibbitt reports on a similarly effective measure used by O'Donnell referred to as the "Littlestep" technique. (Ibbitt, 1970, p. 162).

attempt at changing a parameter value is defined as a step or trial, whether or not a success or failure occurred. This allowed a measure of relative time involved. (3) Convergence criteria - There is no automatic convergence criteria. The parameter incrementation process proceeds until the number of trials exceeds a selected limit. This was done because it was noted that most of the changes in OF occurred during the early portion of fitting as the step size decreased with increasing number of steps (Dawdy and O'Donnell, 1965). Convergence is judged by examining plots comparing observed with computed flows, and the value of the standard error.[12/] The plots used are of two types. One type of plot available is a scatter diagram of observed peaks or storm volumes versus the simulated values. A second type of plot is a hydrograph plot showing both observed and simulated discharge ordinates for a storm event. Calibration runs may be continued, using previous runs as starting points, until the user is satisfied with convergence.

12/ Dawdy et al., 1972, contend that an accuracy of about 30 percent standard error is obtainable (p. B27) where standard error is defined as standard error of estimate, SEE, which is given by

$$SEE = \sqrt{\frac{\Sigma(Y - Y')^2}{N}}$$

where Y is the measured flow, Y' is the simulated flow and N is the number of events. When Y and Y' are expressed in logarithms to the base 10, SEE may have units of percent by computing the average of the antilogarithms of the positive and negative square root.

This modified Rosenbrock technique is applied to the calibration process by considering three rounds of fitting. These rounds are implied by the three objective functions, equations (II.13) through (II.15). The first round fits the seven member volume producer parameter set. Thus, equation (II.13), OF_1, is structured to minimize differences in computed and observed volumes. The ending values of this parameter set is obtained and used as the starting point for the third round. The second round fits the three surface routing parameters. Thus, equation (II.14), OF_2, is designed to minimize differences in computed and observed peaks, without effect from erroneous simulated volumes. As indicated, the exclusion of these three surface routing parameters from volume fitting is warranted as they have no effect on computations of rainfall excess. This exclusion eliminates the chance of "curve-fitting" adjustments by these parameters for volume reproduction purposes. However, as the volume producer parameters do effect peaks, the third round of fitting is necessary in order that the observed peak will be reproduced. The surface routing parameters are held at the constant value determined in round two for this round. Thus, equation (II.15), OF_3, is used to adjust the volume producer parameter values from round one to give the correct peak. OF_3 represents the error in peak reproduction and denotes the accuracy of the overall optimization process.

(3) Verification of Optimal Parameter Values. Verification has been accomplished at several levels: (a) acceptance of parameter values due to satisfaction with convergence criteria results,

(b) visual inspection of hydrograph computations (i.e., includes plots of complete hydrograph, computed and observed storm runoff, and storm peaks) and statistical analysis comparing computed and observed data, and (c) use of split sampling tests so that calibration is performed on one sample and verification on another. Approach (a) is the weakest approach to verify parameters. Approach (b) has been the most common approach used and it does allow the user to "see" the results. Approach (c) is the most strenuous, and should be the approach taken; however, it may not be warranted due to lack of data. Assuming two samples, optimal parameter values could be determined for both sets and then verified on the other. The added expense of recalibration required and the necessity for more data has subjected this approach to a limited number of test cases.

Summary of Parameter Optimization Process. This section reviews the three step process used to determine optimal parameter values. The manner in which it has been applied to the Model is presented so that a background may be developed for judging the stability of parameter values so determined. There are opportunities for errors, inaccuracies and interactions to affect the final parameter values at each of these three steps. As this optimization process will produce the parameter values needed for determining relationships of parameters versus basin characteristics, knowledge of the process must be used to aid in assessing physical significance given to the "optimally" determined parameters.

Examples of Model Usage

This section presents a brief review of how the Model has been applied in the past. It is not intended to present summaries of the conclusions of these past studies, but to emphasize "how" and "why" the Model was used and comment on parameter evaluation.

In general, conceptual hydrologic mathematical models have the following applications (Dawdy et al., 1972):

(1) Extension of streamflow records in time - This requires the use of National Weather Service long-term rainfall data (or comparative source) to be applied to model parameters defined at the streamflow site of concern, where the streamflow record is shorter than the long-term rainfall record.

(2) Synthesis of information for ungaged sites - This requires the use of relationships equating physical basin characteristics with model parameters in order that observed or synthetic rainfall records may be applied for the site, and information gained about this ungaged site.

(3) Measure effects of man-made changes on basin hydrology - This requires the comparison of results "before" the change with those "after". Such a comparison could be accomplished in several ways including the use of model parameters determined by predicting how change will effect the relationships between basin characteristics and model parameters.

It should be noted that item (2) and an approach to item (3) will benefit from this thesis. However, the use of the Model to date has been almost exclusively under the category of extending streamflow records in time.

The use of the Model to extend streamflow records in time has been applied in the joint USGS-Federal Highway Administration program to study flow characteristics from small drainage basins in individual states so that design flow may be determined for bridge or culvert design. As this program did not start until the early 1960's in most cases, there was a lack of streamflow data to derive meaningful flood frequency relationships. The advent of the Model allowed the program to be geared to collecting at-site data for calibration purposes, and then use long-term precipitation data to extend the discharge record. A flood frequency curve was then determined by applying a Log Pearson Type III fit. The resulting discharges at the recurrence interval of concern were then regressed against drainage basin indices such as area, slope, channel length, elevation, forest cover, annual rainfall, and others. The resulting regression equations were used to determine design flows for specific return intervals as ungaged sites. This is the same procedure as outlined in Chapter I.

The joint USGS-FHA program has been completed in several states. These applications of the Model are, by far, the most numerous examples of its use. Two examples are those reported by

McCain (1974) for Alabama and by Hauth (1974) for Missouri. McCain worked with 21 sites which ranged from 1.42 to 15.9 square miles in size and 5 to 21 years of recorded data (majority had about 9 years). Hauth had a data base of 43 sites which ranged from 0.14 to 8.36 square miles in area, and 3 to 24 years of recorded data (majority had about 7 years). Both of these users eliminated storms from calibration which did not appear to cover the basin. Initial parameter values were selected on basis of climate, geology, soil and basin cover. McCain found, for Alabama, that the following general relations held for parameters:

(a) PSP ranged from 1.43 to 9.04 with minimum for chalky area with highly plastic soils, and high for area with deep sand.

(b) Similarly, KSAT ranged from 0.04 inches per hour for clay soils to 0.15 for sandy loam soils. These values were felt to be reasonable as they approached these cited by Musgrave (1955).[13/]

(c) BMSM ranged from 1.6 to 13.7 inches with the highest values derived for sandy basins.

(d) DRN and TP did not show any apparent physical trend.

(e) EVC and RR fell in the range of 0.6 to 0.9 with some minor fitting tendencies exhibited.

13/ Musgrave lists values of 0.05 to 0.10 inches per hour for silt loam and 0.20 to 0.30 inches per hour for sandy loam.

(f) KSW ranged in value from 0.71 to 8.1 and did not agree with computed values

(g) TC appeared reasonable and agreed with its measured values.

Hauth concluded that the parameter values derived from this calibration process did indicate a "rational consistency of parameter values from basin to basin". Hauth's accuracy of the calibrated fit was on the average of about a 35 percent standard error.[14/] McCain's ranged from 17 to 48 percent standard error and averaged 30 percent. They both imply a physical basis for the parameters.

Other examples of Model usage include Dempster's (1973) application to an urban area in which flood frequency was determined as a function of effective imperviousness and drainage area by using a more distributed version of the Model with multiple raingage input. Dempster found an average standard error for the calibrated fit of 26 percent which is probably attributable to the distributed nature of this version. Myrick et al., 1977, (in preparation) have applied the Model in a "before" and "after" study to evaluate the effects of juniper and pinyon eradication in Arizona. The Model was modified to give a more detailed accounting of the soil moisture profile.

14/

Equation (II.15), OF_3, gives the total error for a calibration. By dividing OF_3 by #FE, the number of flood events used in calibration, and computing the square root, the total error may be expressed as a standard error in percent as indicated by footnote No. 12 of this chapter. This percent standard error is used throughout the study as a measure of "goodness" of calibration.

Those examples show how the Model has been applied in the past. Emphasis was placed on the USGA-FHA program studies, as exemplified by the McCain and Hauth reports, because they use the same version of the Model, and they represent those studies which serve as the data source for calibrated parameter values.

Study Area Definition

This study is an attempt to relate Model parameters to the physical characteristics of a basin. As mentioned above, the Model parameters have been defined in the USGS-FHA program. In order that the development of relationships between the parameters and basin characteristics might be defined on a regional basis, the definition of the study area required data from drainage basins within a definable region. Fortunately, state programs for six states within a general region were available (Figure 8). The states of Georgia, Alabama, Mississippi, Tennessee, Missouri and Illinois. A total of 344 drainage basins were available for these states. A breakdown by states of the number of drainage basins and USGS-FHA program report available is presented in Table 1.

These 344 sites served as the source for definition of the parameter values. Unfortunately, problems arising within the calibration process or upon the definition of basin characteristics lead to the elimination of sites. The final site selection is presented in subsequent chapters.

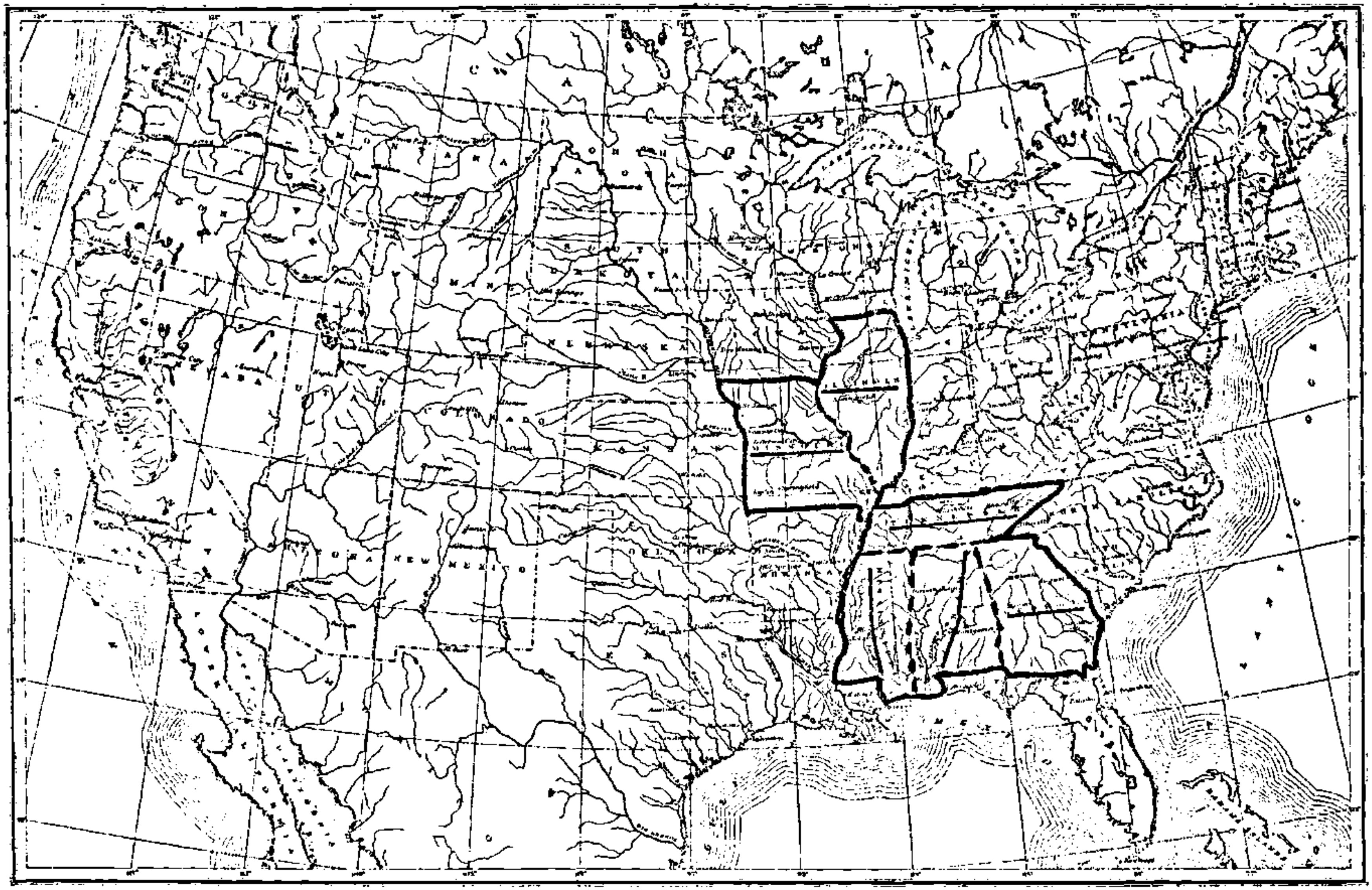

Figure 8. Map of Study Area

Table 1. Number of Drainage Basins Calibrated for Study Area

Sample	Number of Drainage Basins Calibrated	Report Reference
Alabama	38	McCain (1974), Olin and Bingham (1977)
Georgia	81	Golden and Price (1976)
Illinois	34	Curtis (1977)
Mississippi	96	Colson and Hudson (1976)
Missouri	43	Hauth (1974)
Tennessee	52	Wibben (1976a)

Summary

This chapter has described the Model and its operation. The process for optimization of the Model parameters is presented so that calibrations may be evaluated. Examples of Model usage are presented with emphasis placed on the USGS-FHA program. This program has provided the source data for defining the parameter values. The study area is defined and report sources for Model calibration results are given. It is left to subsequent chapters to describe the relative importance of Model parameters, and evaluate Model calibrations.

CHAPTER III

LITERATURE REVIEW

Introduction

A search of currently available literature was conducted in order that pertinent information could be obtained for application to this dissertation. This chapter presents a summary of the information obtained. Information which requires further investigation will be indicated in the text, and the actual investigation will be presented in subsequent chapters.

This chapter is presented with two main focal points. The first of these is concerned with the determination of the significance of the parameter values. As indicated in Chapter I, this is a major thrust of this research in order that the parameters may be related to basin characteristics. The areas of concern under this heading are (1) model adequacy, (2) methodology for determining optimal parameter values, and (3) the effects of data errors. The second focal point allows an insight into previous attempts at relating the parameter values of conceptual rainfall-runoff models to basin characteristics. These attempts are briefly reviewed with respect to the approach taken and the adequacy of the approach. A discussion on how this study might apply some of the methodology presented in these other attempts to relate parameters to basin characteristics and how this study might avoid some of the problems which these attempts encountered is presented.

Determination of the Physical Significance of Model Parameter Values

The conceptual rainfall-runoff model is intended to represent physical hydrologic phenomena. The model's components are supposed to be valid representations of the actual physical processes. The parameters are supposed to represent physical characteristics of the basin that control the rate at which those processes occur. However, if the process modeled does not employ relationships that represent the true functioning of these physical processes, the parameter values are not indicative of physical measures. In a more comprehensive analysis, Amorocho and Hart (1964) noted that this lack of reliability was the result of (a) imperfections in the model, (b) non-uniqueness of the model simulation process, (c) errors in recorded data, and (d) effects of spatial distributions of parameters. These sources of error in determining the physical significance of parameters will be dealt with in the following sections. The section "Model adequacy", attempts to judge the adequacy of the Model and investigate imperfections in models, the non-uniqueness of the synthesis process, and the effects of spatial distributions of parameters in an attempt to evaluate the Model. The section entitled "Methodology for determining optimal parameter values" views the documented methods in light of their effect on the non-uniqueness of the modeling process. The last section, "The effects of data erros", presents the findings of how errors in recorded data have affected model use in order that realistic bounds may be placed on model calibrations and use.

Model Adequacy

A conceptual rainfall-runoff model may be considered adequate if it meets the following conditions: (1) The model components truly represent hydrologic phenomena, and (2) the model produces an acceptable response. The first of these is required if the model is to be termed "conceptual" rather than "black box", and the second must occur for any model to be adequate.

As indicated in previous chapters, the components of the Rainfall-Runoff Model are quite similar to those of most models developed since the advent of the lumped parametric conceptual rainfall-runoff model published by Crawford and Linsley in 1962. The models developed since 1962 may be separated into the following general categories: (1) Stanford Watershed Model (SWM), (2) Boughton Model, (3) Dawdy-O'Donnell Model, and (4) miscellaneous. A sampling of actual models developed within these categories are presented in the following references:

(1) SWM type

- (a) SWM Mark II, Crawford-Linsley, 1962.
- (b) SWM Mark IV, Crawford-Linsley, 1966.
- (c) Kentucky Watershed Model (KWM), James, 1970; Liou, 1970; and Ross, 1970.
- (d) Daily version of SWM, Wood and Sutherland, 1970.
- (e) Modified SWM, version developed by Ibbitt, Ibbitt, 1970.

(f) Georgia Tech Watershed Simulation Model (one of several different adaptations of SWM developed at universities as a teaching and research aid), Lumb et al., 1975.

(2) Boughton Model

(a) Boughton Model, Boughton, 1965.

(b) Modified for humid climate, Murray, 1970.

(c) Segmented version, Chidley-Goodwill, 1975.

(3) Dawdy-O'Donnell Model

(a) Dawdy-O'Donnell Model, Dawdy'O'Donnell, 1965.

(b) Small basin flood simulator, Lichty, et al., 1968.

(c) Modified Dawdy-O'Donnell Model, version developed by Ibbitt, Ibbitt, 1970.

(d) USGS Rainfall-Runoff Model, Dawdy et al., 1972.

(4) Miscellaneous

(a) Model proposed for Australian representative basins program, Chapman, 1968.

(b) Nash et al. Model(s), Nash et al., 1970; O'Connell, et al., 1970; and Mandeville et al., 1970.

(c) Porter-McMahon Model, Porter and McMahon, 1971.

(d) Bergstrom-Forsman Model, Bergstrom and Forsman, 1973.

These models represent the rainfall-runoff process by components describing soil moisture accumulation in various storages (e.g., surface, upper, lower) where inflow to these storages is determined by infiltration from the higher storages and outflow from these storages is controlled by drainage to lower storages and evapotranspiration. For the models concerned with the streamflow hydrograph, routing of the moisture in excess of the storage value(s)[1/] has been accomplished by using previously developed and thoroughly tested methods (i.e., Clark, 1945; Nash, 1958; Dooge, 1959; O'Donnell, 1960; Wooding, 1965). The critical portion of these models has been, in general, the soil moisture accounting part, and, in particular, the methodology used in representing infiltration.[2/] For the most part, infiltration has been represented by adjusting parameter values for an expression that provides a good representation of local infiltration in such a manner that average area wide infiltration is better represented. Two examples which have yielded good results for point infiltration and, as a result, have been applied on an area wide basis are the approaches of Horton (1939) and Philip (1954). There have been exceptions to this type approach such as the replacement of infiltration by retention theory (Bell, 1966; Synder, 1971) or the use of indirect measures of infiltration (O'Connell, et al., 1970;

[1/] The Broughton type Models and the Chapman Model are concerned with runoff volumes only; no routing component was used.

[2/] The contention that the soil moisture accounting and infiltration component is the most important for rural watersheds is supported by the following: (a) Sensitivities reported in Dawdy and O'Donnell, 1965; (b) Implied from decision to "fit" three soil moisture accounting parameters (out of total of four fitted) in Crawford-Linsley, 1966; (c) Discussion on evaluating parameters in Boughton, 1968; (d) Analysis of sensitivities with respect to Phillip equation reported in Dawdy and Lichty, 1968; (e) Listing of two most critical parameters reported in James, 1972.

Mandeville et al., 1970; Nielsen and Hanson, 1973). These exceptions can rightly argue that the lack of sufficient sophisticated data networks makes it difficult to validate the more sophisticated approach. However, these descriptions of infiltration have been validated in the laboratory and, thus, their users have applied them due to this physical validity. Thus, it is concluded that these models, including the one of concern, do adhere to recognized theory of hydrologic phenomena.

Admittedly this condition of adequacy is met with a degree of concern towards the factors affecting lack of reliability pointed out by Amorocho and Hart (1964), especially the imperfections in the model and the non-uniqueness of the modeling process. However, the acceptance accorded these models does exhibit satisfaction with model response. The lack of actual verification studies with statement of accuracy may have attributed to this acceptance. Dawdy et al. (1972) states an obtainable accuracy of 30% for matching observed and simulated peaks for this Model. Ibbitt (1970) compared modified versions of the Dawdy-O'Donnell Model and SWM with the conclusions that (a) the models had very similar basic characteristics, i.e., indicating a consistent interpretation of hydrology,[3/] and (b) the modified SWM was to be preferred over the less complex, i.e., fewer parameters, Dawdy-O'Donnell Model.[4/] The fact that a model with more

[3/] From Ibbitt, 1970, p. 185.

[4/] From Ibbitt, 1970, p. 205.

parameters fits a data set better than one with less is not surprising; however, the agreement in interpretation of hydrology does give credence to the structure of these models. Other modelers have stated their acceptance of model response by various measures, e.g., correlation coefficients between observed and simulated flow and agreements with plotted hydrographs. The use of split-sampling[5/] methods for checking model response has also been employed (Litchty et al., 1968; Crawford and Linsley, 1966; Murray, 1970; Porter and McMahon, 1975). Thus while there have been few unqualified statements of accuracy, the overall consensus of the modelling results surveyed was an acceptance of the model reponse.[6/] Thus, it is concluded that these models, including the one of concern, can produce acceptable responses.

The above discussion has concluded that this Model is adequate according to the criteria stated. However, the reasoning presented is to a degree subjective and self-fulfilling. Basically, the apprehensions to physical models suggested by Amorocho and Hart have

[5/] "Split-Sampling" refers to the use of two data sets: the first to determine optimized parameter values and the second to verify these values.

[6/] The reason for acceptance of this model response, however, does seem in part related to the physical conceptual nature of the models. A statement from the Nash and Sutcliffe study (O'Connell et al., 1970) supports this as the Layered Model is preferred over the modified Rational Method due to its physical analogy even though comparisons of them showed no significant difference.

not been considered. Accepting the contention that the model structure is based on recognized hydrologic theory and it can produce acceptable results does not mean that the model parameters relate to watershed characteristics controlling the physical processes. Without considering the effects of data errors here, the remaining items suggested by Amorocho and Hart help illustrate this.

The Model is imperfect for two reasons. First, while the Model can be said to adhere to recognized hydrologic theory, the fact that current hydrologic theory is not the ultimate allows for imperfections to enter the model structure. Hydrologic theory is an evolving process as witnessed by the representation of infiltration, i.e., the Horton formulation (Horton, 1939), which was derived as an empirical approach, has been replaced by the Philip equation (Philip, 1954) in this Model as it was based on more physically rigid theory.[7/] Second, constraints caused by time and money do not allow the representation of the hydrologic theory in the most complete terms. This inability to model with more sophisticated mathematics is usually necessitated by the lack of sufficient data to verify the additional computations. Improved computers and better data networks could alleviate this reason for model imperfections.

The non-uniqueness of the synthesis process which refers to the fact that different models can produce similar results should

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[7/] It could also be contended that this too is an empirical approach as it is based on the analysis of observed data (Nelder, 1972, p. 368).

come as no surprise. This follows from considering the many different conceptual rainfall-runoff models mentioned earlier, the fact that these models are in various states of change, and the other approaches to simulation such as "black box" models and statistical models. The fact that the synthesis process is not unique helps to further illustrate the complexity and interdependent nature of the system being modelled. This in turn bids caution in attaching a "physical signficant label" to model parameters without thoroughly inspecting model response. The use of sensitivity analysis has been suggested as a means of viewing parameter effect on model response (Vermuri et al., 1969; McCuen, 1973). Sensitivity analysis has been used with conceptual rainfall-runoff models to assess the contribution and significance of parameters (Dawdy and O'Donnell, 1965; Lichty, et al., 1968; Chapman, 1968; Plinston, 1972; Dawdy, et al., 1972; Leavesley, 1973). There have also been attempts to view the response surface of the model and use this to evaluate individual parameters and their interdependencies (Ibbitt, 1970; Plinston, 1972; Carlson, 1972; Johnston and Pilgrim, 1973; Bergstrom and Forsman, 1973). These studies lay the foundation for the consideration of parameter sensitivity and parameter interaction within this dissertation to gain insight into the physical significance and stability of this Model's parameter values.

The effects of the spatial distribution of the parameter causes derived parameter values to be, at best, average values for the basin (Dawdy, et al., 1972). This is a result to be expected for any lumped parametric model. There are attempts to relate point parameter values to a basin-wide average (Crawford and Linsley, 1966; Dawdy et al., 1972). However, most parameters are assumed to apply over the entire basin. There are some obvious methods to attempt to alleviate this, i.e., choose smaller drainage areas which are homogeneous. Yet for the most part, spatial distribution will continue to influence a lumped parametric model, and must be considered when labeling a parameter as physically significant or not.

In conclusion, the Model is judged to be adequate. While it has its limitations as enumerated above, it is based on recognized explanations of hydrologic phenomena and it can produce acceptable flow simulations. The physical significance of the parameters does not necessarily follow. However, restriction of parameter values to observed ranges and recognition that lumped parameter values produced by calibration techniques represent basin averages do allow the properly defined parameter to be considered physically significant. The properly defined parameter depends on not only the manner in which the parameter value is determined but also the stability of the parameter value.

Methodology for Determining Optimal Parameter Values

As mentioned in Chapter I, the methodology for determining optimal parameter values may be described as a three step process. These include (A) selection of a data base, (B) determination of the optimal parameter data set, and (C) verification of these optimal parameter values. Each of these allow errors to affect the "real" parameter values and, thus, the uniqueness of the model to be applied to a basin. It is possible that variation in any of these steps would lead to determination of other parameter sets which fit the data equally well (Ibbitt, 1970). Thus, the three steps are discussed below with this in mind, and with the intent of improving the methodology for determining optimal parameter values of the Rainfall-Runoff Model.

(A) Selection of Data Base. The selection of a data base requires a basin with adequate record to insure that the fitting techniques used will have sufficient degrees of freedom. For the Model, the basin must have sufficient storm event data for a number of storms in excess of the number of parameters. Dawdy, Lichty and Bergmann (1972) stated the Model was for small drainage areas (less than 10 square miles) to overcome problems with spatial variation of rainfall. The use of small, homogeneous basins may also be used to alleviate some of the problems with the spatial distribution of parameters. It is also important that the data chosen for calibration covers the entire range of flow events which the Model is attempting to reproduce. This should insure that all of the Model parameters are activated, and, thus, no parameters will act as "nuisance"[8/] parameters. For a continuous model, the

[8/] "Nuisance" parameters are defined as those which do not enter into a model component's response. They may be either a threshold value which is never operative or one which represent a bounded concept which has meaning while within bounds but none outside the bounds (Ibbitt and O'Donnell, 1971).

Kentucky Watershed Model, Liou (1970) suggests that 3 years of data be used, i.e., one with largest December-May flood, one with largest June-November flood and year with least summer runoff. For the U.S.G.S. Model, a flood peak simulator, it is felt that the range of storm events should include flow of low and high values, relative to the recorded data, produced by rainfall events in wet and dry moisture conditions.

(B) Determining Optimal Parameters. The determination of the parameter set is composed of two requirements (a) a criteria to judge best fit, i.e., minimize an error measuring objective function, and (b) a technique to adjust the parameters so that the best fit criteria will be satisfied. These requirements affect the resulting value of the parameters in that the first defines the shape of the response surface searched, and, thus, the combined effect of each parameter, whereas the second determines how efficiently the optimal point on the response surface is located. In order to gain an insight into how these might be changed for the U.S.G.S. Model, the model categories previously enumerated, Stanford Watershed Model (SWM), Boughton Model, Dawdy-O'Donnell Model and miscellaneous, are reviewed. A summary of applicable points are presented which will be investigated in subsequent chapters for this model.

(1) Stanford Watershed Model -- The initial reports by Crawford and Linsley (1962, 1966) show that these requirements were met by comparing continuous plots of observed and simulated daily flows and monthly volumes using trial-and-error adjustments to the

parameters which could not be determined exogenously. As only four parameters had to be fit by trial-and-error (Crawford and Linsley, 1966, p. 69), the effects of parameter interaction and sensitivity could be reduced.

Subsequent application of SWM, however, could not make this same claim. Fleming (1970) noted that trial-and-error must be used to fit 12 of the model parameters. This would increase the effect of parameter interaction and sensitivity on the final values and produce less confidence in the results. Though tempered by applying guidelines from Crawford and Linsley, the parameter values would still be quite subjective, and unstable.

James, in an attempt to remove this subjectivity, instigated the development of an automatic method for determining parameter values, OPSET (Liou, 1970). OPSET fits 13 parameters by a computerized trial-and-error procedure in which each parameter is fit to the kinds of modeled flows to which the parameter is most sensitive. The error function form minimized is a sum of the squares of normalized differences between observed and simulated flow measures determined in the pertinent component.

Munro (1971) adapted the search technique developed by Hooke and Jeeves (1961), Pattern Search, for use by the National Weather Service version of SWM. Lumb et al. (1975) present an application of Pattern Search to a modified version of SWM. It appears that Pattern Search offers more flecibility than OPSET.

(2) Boughton Model -- Boughton advocates use of a steepest

descent search method to minimize his objective function (Boughton, 1965). Upon application to his objective function, sum of squares of differences between observed and simulated monthly totals of runoff, he discovered that this gave too much weight to peak flows (Boughton, 1968). Boughton also analyzed the work of Dawdy-O'Donnell (1965) on sensitivities and concluded that the more sensitive components of his model should have their parameters optimized first. This appears to be necessary for certain fitting techniques (e.g., steepest descent, univariate, trial-and-error).

Murray (1970), in adapting the Boughton Model, chose the Rosenbrock Method which can better handle the interdependencies among parameters. He also found that the order in which parameters were optimized affected the results, and thus, ordered his parameters in a subjective manner to account for this. However, it appears that an attempt to apply sensitivity studies or use of a "phase" approach would have been more acceptable. Murray selected a more sensitive objective function than Boughton, sum of squares of differences in observed and simulated daily flows, which can affect the optimization technique.

The study completed by Johnston and Pilgrim (1973) on the Boughton Model provided further insight into fitting methods and objective functions. They tested both direct search methods and descent methods.[9/] They concluded that the best technique was the use of a combination to take advantage of each methods strong points. The two chosen were the Simplex Method of Nelder and Mead, and Davidon's Conjugate Direction Method. The Simplex Method rapidly converges to a valley floor defined by the response surface but, because it may have problems traveling down the valley, the Davidon Method was employed to handle this situation. They also investigated different forms for the objective function using the less sensitive monthly runoff volumes (i.e., as opposed to daily volumes used by Murray), observed, V_{oi}, and simulated, V_{si}. First they inspected forming the objective function from deviations and changing the exponent j, i.e., O.F. = $\sum_{i=1}^{k} (V_{oi} - V_{si})^j$. This changed scaling of the response surface but did not alter the minimum point. For j in the range (0, 1), they found response surface to be much too flat for a conclusive search of it. For j = 2 or more, these problems did not occur; thus, they concluded that j = 2 was as "good or better". Second and last they applied transforms to the monthly volume, i.e., O.F. = $\sum_{i=1}^{k} (V_{oi}^m - V_{si}^m)^2$. This affected the actual optimum value of the parameters. For m = $\frac{1}{2}$, they found that small events were favored; for m = 2 the large events were favored. As they did not want to bias the model toward high or low events, m was chosen equal to 1.

[9/] The direct search methods tested were (1) a univariate type, (2) Rosenbrock, and (3) a simplex method proposed by Nelder and Mead (1965). The descent methods attempted were (1) a univariate-relaxation method, (2) a steepest descent method, and (3) a conjugate direction method proposed by Davidon (1959).

Thus, the form of the objective function used was $O.F. = \sum_{i=1}^{k} (V_{oi} - V_{si})^2$.

(3) Dawdy-O'Donnell Model -- The paper by Dawdy and O'Donnell in 1965 not only introduced the predecessor to the Model, but also was the first attempt to use an automatic optimization technique for determining the best set of parameter values for the use of conceptual rainfall-runoff models. The optimizing method used was the technique developed by Rosenbrock (1960) and the objective function used consisted of the sum of squares of differences between observed and simulated runoffs for each interval of the record. This paper also introduces the use of sensitivity as a possible aid in optimization as it concludes that "the greater the sensitivity of the model response to a parameter, the closer and sooner will that parameter be optimized". Dawdy-O'Donnell emphasized the following: (1) Use alternate means of checking parameter values to insure physical significance; (2) parameter values derived will depend on data used; (3) efforts toward using an objective fitting procedure are necessary if fitted values are to be correlated with basin properties so that subjective reasoning will not "build in" assumed correlations; (4) stressed development of physically meaningful components; and (5) cautioned that a minimum objective function cannot be the only criteria of a fit (as data errors will effect the objective function value), but must consider some measure of response sensitivity (including use of sensitivity in judging a convergence).

Dawdy and Thompson (1967) pointed out that insensitive parameters allow little physical interpretation and possibly indicate that the model should be simplified by removing them. Dawdy (1968) stressed the reliance of the determined parameter values on the objective function form used. He shows an example of the effect of choosing two different objective functions. The first minimized the sum of squares of the differences between simulated and observed peaks and the second minimized the sum of squares of differences between simulated and observed daily discharges. Though the Model was developed to estimate peak discharges, fitting to peaks produced a bias (Model consistently produced higher peak values than those observed) while fitting to daily flows did not produce this bias (plot of observed versus simulated peaks showed random scatter).

Lichty et al. (1968) also using the Rosenbrock technique and an objective function defined as a combination of both volume and peak errors, i.e., O.F. = 0.50 OF_1 + OF_2 where OF_1 and OF_2 are given by equations (II.13) and (II.14). No mention was made that this single phase fitting (simultaneously fitting both volumes and peaks) may introduce curve fitting errors due to the presence of interaction between parameters concerned with peaks and those concerned with volumes. The conclusions were that the antecedent moisture accounting parameters (RR, EVC, and DRN) grossly influenced the value of O.F. while the infiltration parameters, PSP and KSAT, and the routing coefficient, KSW, were secondary in importance (version did not have TC or TP/TC). The other parameters, RGF and BMSM, had little or no influence, and may be poorly defined. These conclusions have severe implications with respect to Model structure and parameter physical significance if accepted at face value for they show that the poorest conceived physical component is the most sensitive. However, it is felt that the form of the objective function used was questionable as it introduced parameter interaction not present in the Model (e.g., KSW is not allowed to influence runoff volume directly). This paper also illustrates that a sufficient number of events is not the only requirement to obtain "good" parameter values. A wide range in both antecedent and storm event conditions must be obtained so that all portions of the Model may be activated.

Ibbitt (1970), using his modified version of the Dawdy-O'Donnell Model, investigated nine different search techniques[10/] and several forms of the objective function. He concluded that a modified version of the Rosenbrock method was the best of those tested. However, he did state that a random search method, similar to that described by Karnopp (1963) should probably be used initially followed by the use

[10/] Methods tested by Ibbitt included the following:

(1) Univariate Search by Beard (1967).
(2) Rotating Coordinates by Rosenbrock (1960).
(3) A modified Rosenbrock by McConalogue.
(4) Direct Search with Conjugate Directions by Powell (1965).
(5) Deflected Gradient by Fletcher and Powell (1963).
(6) Imperial Chemical Industries Least Squares by Wales.
(7) Version of Levenberg's Least Squares by Margquardt (1965).
(8) Least squares by Powell (1964).
(9) Random Search Method by Karnopp (1963).

of his version of the Rosenbrock method.[11/] Ibbitt's version of the Rosenbrock method does not appear to be identical to that used in this Model.[12/] However, the differences appear minor. He also investigated various objective functions including the following: (a) sum of squares of differences between observed and simulated (no transform), (b) sum of absolute values of these differences, (c) sum of squares of differences raised to a power, k, to increase emphasis on larger ordinates, and (d) sum of squares of differences divided by oberved raised to some power, n, as n = 1 gave equal consideration to all ordinates, while n > 1 allows fitting smaller ordinates better. He concluded that form (a) was best for his purposes as it had statistical significance for linear models (also noted in Dawdy et al., 1972) and favored his objective of forecasting flood peaks. Of the others, he found that only form (b) exhibited the ability to reduce the real difference between observed and simulated flows when the objective function value was reduced. Ibbitt also investigated the problems which confront search techniques attempting to follow the response surface. These are presented in

[11/] This approach is also supported in a later paper, Ibbitt and O'Donnell, 1971. While it is believed that the stochastic-direct search has advantages, the constraints of time and money prevented further investigation with "dual" search techniques for this dissertation.

[12/] Ibbitt rejected the use of "Littlestep" as it did not appreciably change his results (Ibbitt, 1970, p. 162-163).

his dissertation (Ibbitt, 1970) and in a paper by Ibbitt and O'Donnell, 1971. They may be summarized as follows: (1) Local optima, which may "fool" a search technique, are caused by the complexity of the model and by serial correlation within the data set. Adjustments to the fit may be made by placing strict and realistic limits upon values which parameters may attain. Also, the problems of local optima can be reduced by increasing the amount of data used in the fitting. (2) Saddle points have a minimum in one direction and a maximum in other, and they may be handled by proper programming checks. (3) Nuisance parameters (see footnote no. 8, Chapter III) reveal themselves as insensitive directions in the search, and they may be handled by using sufficient data and proper model structure. (4) The global optimum represented on the response surface by long inclined valleys reveal parameter interactions and may be handled by accounting for these interdependencies by modifying the model structure.

Dawdy et al. (1972) emphasizes the need to check fitted parameter values with similar measures from other sources. This aids in checking the physical significance of the parameters. Dawdy also presents some results obtained by fitting with Rosenbrock to objective function OF_3 (equation II.15), which may be referred to as fitting to the flood peak discharge values. Sensitivity plots showed that KSW, PSP, RGF, BMSM, and RR were quite sensitive; EVC moderately sensitive and DRN and KSAT, insensitive. It is interesting to note that the hierarchy of sensitivity indicated differs from that shown above by Lichty et al. (1968) for a different objective function and a different data set. These differences in the sensitivity hierarchy are attributed to the influences of the objective function form and data set composition. For the same data set, the objective function form determines the shape of the response surface subject to a search by an optimization routine. For the same objective function form, the data set composition can also affect the shape of the response surface as indicated above by Johnston and Pilgrim (1973) and Ibbitt (1970). Changing the shape of the response surface can alter the fitted parameter values which may affect the sensitivity hierarchy. This possible variation in parameter values (and sensitivity) requires that the objective function form and the data set composition be investigated for this Model. The resulting information can be applied to aid the evaluation of parameter calibrations.

(4) Miscellaneous -- Chapman (1968) advocates fitting of parameters only over a conceptual range of values which would build in physical signficance. He also states that parameters which do not vary with time should be fit exogenously, while others should be determined by fitting to observed data. Chapman (1970) later investigated methods of optimizing, which included univariate, steepest descent and the Simplex Method by Nelder and Mead. He found that the Simplex Method was best as it did not require computation of gradients and it can be expected to achieve a global minimum if the original simplex fills a reasonable amount of the

available parameter hyperspace. Upon investigating an objective function, he noted that the outliers should not be allowed to over influence the fit, i.e., storms[13/] which are fitted better should be given more weight. To accomplish this, he applied transforms to his objective function form which was the sum of squares of differences between observed and simulated volumes (Chapman is concerned with volumes only) for each storm event. The transforms attempted were (a) square root, (b) cube foot, and (c) logarithmic. As all accomplished the goal of decreasing the weight on the outliers, he subjectively chose the square root transform.

The Nash et al. study (Nash and Sutcliffe, 1970; O'Connell et al., 1970; Manderville et al., 1970) applied the Rosenbrock search method and the standard sum of squares of differences between measured and simulated to exhibit a methodology for building a model.[14/] This study implies the fitting of parameters based on the results of the component for which it applies. Plinston (1972) analyzes parameter sensitivity and interaction for the models developed in the Nash et al. study. He concluded that sensitivity must be computed about optimum values of parameters, and advocates improving parameter estimates by

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[13/] Chapman uses same approach to time intervals as the U.S.G.S., i.e., days for non-runoff periods and small interval of one-hour or less for runoff on storm days.

[14/] In contrast to building a model, Fleming (1971) and Ibbitt (1970, p. 259) advocate the "pruning" of a general overall model, e.g., SWM by deleting portions not applicable to the basin of concern.

removing or possibly adding parameters to avoid severe interdependencies. He approaches his study by a thorough investigation of the response surface.

Porter and McMahon (1971) appear to be the earliest proponents of a "dual" search technique when they advocate use of the Simplex Method of Nelder and Mead to define region of true optimum and then a combination of univariate adjustments and steepest ascent searchs to determine global optimal values. They also advocate use of sensitivities to determine which parameters to optimize. In a later paper, Porter and McMahon (1975) continue with the "dual" search approach and used objective function criteria involving use of comparisons of monthly mean flows and their standard deviations as computed for observed and simulated monthly flows, comparisons of flow duration curves from observed and simulated flows, and the correlation coefficient between simulated and observed daily flows.

Carlson (1972) and Bergstrom and Forsman (1973) showed the value of analyzing contours of the response surface. Both studies used this approach to find the optimum rather than using an automatic search approach. The objective function criteria was the same, i.e., the standard sum of squares of differences between observed and simulated. Bergstrom and Forsman removed much of parameter interaction by determining 6 to 8 parameters from studies of observed hydrographs or basin characteristics. They emphasized the need to consider stability when determining parameter values by considering sufficiently long record lengths, to account for interaction by expressing one parameter as function of another, and to consider removing insensitive parameters from model.

Leavesley (1973), using the Rosenbrock search method, studied five different forms of the objective function, O.F.[15/] The forms used and conclusions reached are as follows:

$$\text{O.F.} \;=\; \sum_{i=1}^{n} (Q_{si} - Q_{oi})^2 \qquad \text{(III.1)}$$

Equation (III.1) is the standard form mentioned previously. It tends to weight large errors more than smaller one independent of their occurrence at high or low flows.

$$\text{O.F.} \;=\; \sum_{i=1}^{n} (\ln\,(Q_{si} + 1) - \ln\,(Q_{oi} + 1))^2 \qquad \text{(III.2)}$$

Equation (III.2) is the sum of squares of the differences of the logs. It weights errors proportionately to the size of flow.

$$\text{O.F.} \;=\; \sum_{i=1}^{n} |Q_{si} - Q_{oi}| \qquad \text{(III.3)}$$

Equation (III.3) is the sume of the absolute value of the differences. It gives more weight to large errors but not as much as (III.1) while being independent of size of flow.

15/ Leavesley was fitting to mean daily flows. Thus, Q_{si} equals simulated mean daily flow, while Q_{oi} equals observed mean daily flow.

$$O.F. = \sum_{i=1}^{n} \left(\frac{Q_{si} - Q_{oi}}{Q_{oi}}\right)^2 \qquad \text{(III.4)}$$

Equation (III.4) is sum of the squares of relative differences. Like (III.2) it weights errors to size of flow.

$$O.F. = \sum_{i=1}^{n} (\sqrt{Q_{si}} - \sqrt{Q_{oi}})^2 \qquad \text{(III.5)}$$

Equation (III.5) is the sum of squares of differences of square roots. Like equations (III.2) and (III.4) it weights errors to size of flow, but it is a less severe transform than the use of logarithms. Leavesley selected the sum of the absolute value of the differences, i.e., equation (III.3). He also applied sensitivity analysis to view parameter contribution for wet and dry years.

(5) Summary -- The method selected to estimate parameter values is a critical step in deriving meaningful parameter values. In the past, the Model requirements of a fitting technique have been met by use of the modified Rosenbrock technique (Chapter II) and the three phase fitting process involving the objective functions defined by equations (II.13), (II.14) and (II.15) have met the requirement for an error measure function. While these are both correct approaches, it would appear that there are adjustments which should be studied to improve the possibility of determining physically significant parameters. The review of the literature has yielded the following areas in which futher investigation will be conducted:

(a) Fitting techniques

The more efficient fitting techniques will be evaluated. Accepting Ibbitt's conclusion (1970) that the Rosenbrock method was the best of the nine he tested (footnote no. 10, Chapter III), the modified Rosenbrock technique, the Pattern Search Method as modified by Munro (1971) and the Simplex Method of Nelder and Mead (1965) will be investigated. The importance of sensitivity analysis, data set composition and the fact of parameter interaction will be investigated. These investigations will be analyzed to determine whether or not appreciable improvements may be made to the fitting technique.

(b) Forms of objective function(s)

As noted from the literature, the form of the objective function will affect the parameter values chosen by the search technique. The various forms attempted in the literature will be inspected further, and those deemed appropriate will be investigated. It is also apparent that the order in which the model parameters are determined in the fit has an effect on results. In this instance, it appears parameter sensitivity could enter into the fit, and this will be explored further.

(C) Verification of Optimal Parameters. The necessity for verifying the parameter values determined as optimal is apparent upon noting the previous cited effects caused by differing data sets, fitting techniques and objective function form. Verification is required to evaluate not only the physical significance of the parameters but also the effect of using these parameters in prediction. There have been two acceptable approaches used within the literature to accomplish this verification. The first of these is the testing of parameter stability which encompasses determining optimal parameters for a basin over more than one data set. The second involves the use of an optimal parameter set, determined for a basin over one data set, in a prediction mode to compare with another separate data set. Ideally both of these should be applied, i.e., optimize over the multisequences and then check predictions. Both of these may be classified under the general title of split-sampling methods. Split-sampling has been cited as a means to verify parameters since Crawford and Linsley, 1964. The manner in which they have been applied is discussed below.

Lichty et al., 1968, used two separate samples of 8 events each from the same time sequence to fit with the Model. A fit to both samples and to the total sample was done. An attempt was also made to study the sensitivity of the objective function for both the control sample (i.e., used to determine parameters) and the test sample (i.e., used to test the parameters). The results not only aided in studying parameter significance but also was useful in understanding the distribution of error. Dawdy et al. (1972) noted that split-sampling is necessary to determine error of prediction as the assumptions from linear regression theory do not hold for this nonlinear model.[16/]

Murray (1970) used split-sampling to validate the fit determined for the Boughton Model. He used a matching index analogous to the multiple correlation coefficient, R^2 (also used in Nash et al. study). This index is the proportion of variation in observed flows that is provided in the simulated flows:

$$R^2 = \frac{F_o^2 - F_s^2}{F^2} \qquad \text{(III.6)}$$

where F_o^2 is the sum of squared deviations of observed daily flows from the mean daily flow, and F_s^2 is the sum of squared differences between observed and simulated flows. Murray computes this index for both the record used for optimization and for a test period of record. If the two index values agree within a reasonable range, then he is satisfied with the fit. Murray does emphasize that a low value for the objective function, i.e., F_s^2, does not guarantee a "correct" model as a high degree polynomial could be forced to fit the data. Thus, the verification process is a necessity to insure proper fit.

With respect to the index, R^2, used by Murray above and others (Nash et al., 1970; O'Connell et al., 1970; Mandeville et al., 1970),

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[16/] The standard error of estimate for optimization is a measure of error in the data. The standard error of prediction is larger as it includes both measure of lack of fit to data used in optimization and measure of error in fitted parameters. Dawdy et al., 1972, p. B-10.

both Clarke (1973) and Bergstrom and Forsman (1973) caution against over reliance. Clarke feels that the entire pattern of residuals should be studied in order that possible bias may be inspected. Bergstrom and Forsman emphasize obtaining stability in the determination of optimal parameters. They feel that R^2 may be unduly influenced by data from dry years, i.e., due to low initial variance in dry years and small differences in simulated and observed, R^2 will be unrealistically low.

Ibbitt (1970) advocated the use of two indices. These were a coefficient of variation, X, and a measure of relative differences, Y. These were defined as follows:

$$X = \sqrt{Fm}/Q_m \tag{III.7}$$

and

$$Y = \frac{Q_m - Q_s}{Q_m} \tag{III.8}$$

where F, the objective function, was defined as sum of squares of differences between measured and simulated flow; m is the number of time periods over which flow was measured and simulated; Q_m is the total measured flow; and Q_s is the total simulated flow. Prediction was rated as good if X and Y were within 25% of their values computed for the corresponding fitting period. While assessing the fit was more difficult, if did involve split-sampling fitting and then comparing the X- and Y- values and the stability exhibited by the parameters.

This study will evaluate the calibrations available using measures similar to those presented above. Despite their validity, split-sampling methods can only be applied on a limited basis due to the money involved. Other measures, involving statistical appraisal of the relationship between observed and simulated peaks as represented by a plot showing this relationship, will be expanded.[17/] This expanded approach will be detailed in a subsequent chapter. It incorporates several of the measures presented above, although in a different form.

Summary. This section on the "methodology for determining optimal parameter values" has reviewed the literature in an attempt to determine possible means for insuring physically significant parameters. The optimization process is sufficiently noisy to produce nonunique parameter values. In order to gain an insight into possible corrections, the following items, which have been explained in the preceding sub-sections, will be considered in this research. (1) The data base must consist of enough storm events to cover a range of flow, range of soil moisture conditions and opportunities to properly apply fitting techniques. (2) Modified Rosenbrock, Pattern Search and Simplex methods will be investigated. (3) Various objective functions will be studied. (4) Verification of calibrated

[17/] The initial approach for applying the statistical analysis to the scatter diagram of observed versus simulated peaks is attributed to P. H. Carrigan. This initital approach has been used as an aid to verify calibrations since 1975.

parameters sets will consist of evaluating various indices, and by analyzing relationships between observed and simulated results.

The Effects of Data Errors

The determination of parameter values for a conceptual rainfall-runoff model by fitting the model response to recorded data allows the parameters to be influenced by errors in the data. This is one more area of concern when attempting to determine whether or not the fitted parameters have physical significance. Data errors have been separated into two classes (Parmele, 1972) as follows: (1) random errors; and (2) systematic errors. The random errors are assumed to be non-preventable, while the systematic errors are caused by faulty collection or reduction techniques which could be removed. Ibbitt (1972) notes the problems due to serial correlation in hydrologic data which affects parameter values. These may be reduced by selection of long periods of record in which, for the U.S.G.S. Model, the storm events are separated by longer intervals. For the conceptual rainfall-runoff-model, two types of input data are always required, precipitation and evaporation data. When determining optimal parameters, the fitting process also requires runoff data. Thus, the discussion will be presented using the three data types as sub-sections, and, in addition, a closing summary will relate the information presented to the Model.

(A) Precipitation Data. Studies which have dealt with the effects of precipitation data errors are Dawdy, 1968; Dawdy and Bergmann, 1969; Ibbitt, 1972; and Hassett, 1974 (summarized in Lumb et al., 1975). The following approaches were taken and conclusions reached.

(1) Dawdy (1968). Dawdy assumed random errors with a mean equal zero, and a standard deviation of 10% and 20% of the value to which error was applied. These erroneous records were inputted to the Model, and their effect on optimizing the parameters and the objective function noted. Dawdy concludes that the major source of error results from rainfall input data. He attributes this to the difficulties in obtaining an accurate measure of basin rainfall from the single point raingage.

(2) Dawdy and Bergman (1969). Dawdy and Bergmann continued investigating the effect of using single point rainfall to represent the actual spatially varied input. The study was conducted on a 9.7 square mile drainage basin with 3 recording raingages within the basin. Each gage record was used as input to the Model in three forms; (a) data as recorded, (b) data adjusted based on the 3-gage mean annual total, and (c) data adjusted based on the 3-gage mean storm total. Upon calibration, these rainfall data sets gave a range of parameters that were to be expected for this basin. The variability exhibited would affect the feasibility and accuracy of any attempts to relate the parameters to basin characteristics. Basic conclusions reached for this study are (a) bias in rainfall data affects resulting fitted parameter values rather than accuracy of fit, (b) time distributions errors in rainfall (assumed only time errors in record adjusted for storm totals) introduce as much as 20% average errors for simulated flood peaks, and thus, (c) prediction of flood peaks for this basin cannot have better accuracy than about 20% with this Model using data

from a single raingage.

(3) Ibbitt (1972). Ibbitt, using the Dawdy-O'Donnell Model, assumed errors to be random with a normal distribution whose mean was the error-free value and standard deviation was 10% of the error free value. This produced large errors even for hydrologic data. He concluded that the effect of rainfall errors was intermediate in their effect with respect to evaporation and runoff data errors. This was attributed to the fact that rainfall errors are smoothed due to the action of the model components. Ibbitt also concluded that the effect on optimal parameter values due to random errors in the data was not significant.

(4) Hassett (1974). Hassett, using the Georgia Tech Watershed Simulation Model, did not look at random errors but rather at systematic errors. Two types of systematic errors were investigated. These included multiplying the largest storm of the year by 0.7, 0.8, 1.1 and 1.2, and multiplying the entire record by 0.8, 0.9, 1.1 and 1.2. Hassett concluded that the most critical errors were the systematic rainfall data errors applied for an entire year as their effect was cumulative over the period. The systematic error applied to the largest storm had little effect in determining the parameter value. He does concede that systematic errors for a long period of time would most likely not approach ± 20%. He also contends that an individual storm error may exceed 30% by a significant amount. This indicates that prediction of yearly runoff totals would most likely not approach ±20% due to systematic errors. However,

prediction of individual storm event runoff could be substantially in error due to systematic errors.

(B) Evaporation Data. Studies which have dealt with the effects of evaporation or evapotranspiration data errors are Dawdy, 1968; Ibbitt, 1972; and Parmele, 1972. The following approaches were taken and conclusions reached.

(1) Dawdy (1968). Dawdy does not apply the distribution of errors approach used for rainfall. Instead he implied that the effect of errors in evaporation data is not significant due to their less important role when compared to rainfall in the simulation process, and both rainfall and runoff data in the optimization process. The fact that evaporation data is not that well defined both at a point or over a basin is pointed out.

(2) Ibbitt (1972). Ibbitt applied the same technique used for rainfall errors to evaporation data errors. He notes that evaporation data has a bounded feature, i.e., amount of moisture lost by evapotranspiration process is limited by amount available, while both rainfall and runoff apply absolutely, i.e., the entire amount influences the model. The effect of evaporation data errors was found to be the least of those investigated.

(3) Parmele (1972). Parmele using three conceptual rainfall-runoff models (the Hiemstra Model, 1968, and two versions of SWM), investigated both systematic and random potential evapotranspiration (PET) data errors. He attempted tests on PET input biased by a constant +10, +20, -10, and -20% on a daily basis, a normally dis-

tributed random error with a maximum range of ± 50% of daily PET input values added onto daily input, and a combination of these. He concluded that in order that PET data errors do not effect the model response, PET accuracy should be ± 20% if runoff is greater than 40 or 50 inches; if runoff is considerably less, the accuracy should be ± 10%. Influence of PET errors may be more significant during late spring and summer months when dependence on soil moisture availability is more critical. Parmele found that systematic errors are cumulative and can have significant effect whereas random errors are not as significant because other portions of the model dampen their effect.

(C) Runoff Data. Studies which have dealt with the effects of streamflow data errors are Dawdy, 1968; Ibbitt, 1972 and Hassett, 1974. The following approaches were taken and conclusions reached.

(1) Dawdy (1968). Dawdy assumed random errors with a mean equal zero, and a standard deviation of 5% and 10% of the value to which error was applied. These were then applied in the same fashion as with rainfall data errors. While noting the direct effect of runoff data errors on the objective function used in determining parameters, he concludes that runoff errors are not as critical as the rainfall errors because the rainfall errors enter into both the computation of excess and the routing of excess to flow. Dawdy contends that there are less errors in the streamflow data compared to rainfall

data as the values obtained are not point values but representative of the entire basin.

(2) Ibbitt (1972). Ibbitt applied the same technique used for rainfall and evaporation data errors. He concluded that relatively equal errors in rainfall and runoff will not have equal effects. This is attributed to runoff errors directly affecting the objective function which cause larger model error than those in rainfall due to the "smoothing" of rainfall error effect by the action of the model components.

(3) Hassett (1974). Hassett investigated systematic errors of -20 and +20% effecting the three largest peaks within the year. He found the effect of these errors to be major for 2 of 5 parameters and felt that further study was needed. He also felt the results may depend on whether the year used to calibrate is "wet" or "dry".

(D) Summary. The general conclusion that is drawn from reviewing the literature available on the effects of data errors on the determination of optimal parameters values for conceptual rainfall-runoff models is that data errors which occur randomly do not significantly affect parameter values although they affect the length of record required for a good calibration, whereas those which are systematic may cause a significant change in the parameter values depending on their size and the type of data affected. With respect to random data errors, it is felt that errors in rainfall data have the greater effect on model response of the types of data discussed. While Dawdy and Ibbitt disagree on this point, it is assumed that the errors caused by the use of point rainfall to represent the entire basin coupled with the belief that rainfall measuring error exceeds that of streamflow measuring error outweighs the direct influence of runoff on the objective function. Ibbitt does state that the size of random errors to be expected with actual data would not be as large as those used in his study. Random errors in evaporation data are insignificant. Systematic errors for rainfall and evaporation data are cumulative and would have a significant effect if persistent over a period of time. Systematic errors in runoff data are felt to be more confined to certain flow regimes as represented by a poorly defined portion of a stage-discharge relationship and their effect will depend on the form of the objective function used and prevalence of the affected flow. Presence of this type systematic error in runoff data will invalidate parameters calibrated for such data.

These data errors will influence the parameters determined for the Model. It is not felt that continued investigation on data errors can be accomplished during this research. In order to minimize the effects of these errors, the data has been screened to increase its quality by reviewing observed streamflow and rainfall data. It is assumed that this screening process has eliminated the effects of the systematic errors. The conclusion drawn for the effects of random errors allows the acceptance of the determined parameter values physical significance within the limitations imposed by the lumped nature of the input.

Previous Attempts at Relating the Parameter Values of Conceptual Rainfall-Runoff Model to Basin Characteristics

Almost without exception developers of conceptual rainfall-runoff models have encouraged attempts to relate basin characteristics to the calibrated parameter values (Crawford and Linsley, 1962, 1966; Wood and Sutherland, 1970; Boughton, 1965; Murray, 1970; Dawdy and O'Donnell, 1965; Dawdy, 1968; Dawdy et al., 1972; Chapman, 1970; Bergstrom and Forsman, 1973; Porter and McMahon, 1975.) This desire is to be expected because such relationships provide a physically meaningful tool to study the hydrologic response of an ungaged watershed. However, this literature search has found only four studies published for which the development of relationships between the conceptual rainfall-runoff model parameters and the basin characteristics was the proposed goal of the study. Three of these studies, James et al. study, 1970 (James, 1970, Liou, 1970; and Ross, 1970), Ambaruch and Simmons, 1973, and Magette, Shanholtz and Carr, 1976, used the Kentucky version of the Stanford Watershed Model (KWM) developed by James. The other study, Johnston and Pilgrim, 1973, used the Boughton Model. The approaches taken in these studies have been reviewed so that this study might benefit in defining its approach and avoid some of the problems they experienced.

James et al. Study

This study had two objectives, i.e., the development of an objective procedure for determining parameter values, OPSET (Liou, 1970), and the development of relationships between the OPSET -

determined parameter values and basin characteristics (Ross, 1970). Ross approached this objective as follows: (1) Determine best possible estimate of values of parameters by fitting OPSET to at least 3 years of data and averaging the values. (2) Obtain basin characteristics data for 20 Kentucky watersheds (17 rural; 3 urban). (3) Develop relationships by correlating OPSET estimates of parameter values against corresponding basin characteristics as guided by qualitative hydrologic analysis. This approach is discussed below.

By fitting to at least 3 years of data, Ross recognized the variation which parameter sets experience when fit to different data sets. The use of 3 years of data representing varying flow conditions is a method to alleviate parameter sensitivity to input data. An attempt is also made to reduce parameter interaction by fitting parameters to model output from the component in which the parameter is used. However, as some model components can not have their effects on model output directly observed on the basin, this does introduce a degree of subjectivity (e.g., determine amount of interflow). Thus, Ross does attempt to account for parameter sensitivity and interaction in determining his parameter values.

Ross developed his relationships based on the 17 rural basins, while the 3 urban ones were used in an attempt to study urbanization. Only the development of the relationships is considered here. Basin characteristics data consist of three general types, i.e., actual measured data determined from topographic maps, general regional climatological data, and data determined from aerial photographs and soils information. Of the measured basin characteristics selected solely for possible relationship with parameters, Ross considered time of concentration (computed from considering horizontal length from most distant point to outlet and slope between points), main stream length, maximum difference in elevation, a shape factor which is the ratio of axial length to average width, and percent forest cover. Other measured basin characteristics were necessary as input to the model. These included drainage area, channel capacity at outlet, percent impervious area, percent lakes and ponds, overland flow slope and overland flow length. These characteristics were also investigated as to possible relationships with the parameters. Mean annual number of rainy days appear to be only climatological measure used. Soil maps, where available, and county and state soils information were consulted to derive three estimates of basin soils characteristics, average available water capacity (AWC), average permeability (P), and average permeability of the surface layer (P_A).[18/] These characteristics appear to be adequate for describing a basin with the possible exception of more climatological indices and a better vegetation index.

Ross then developed the relationships by considering only those

[18/] These are defined as follows:

(1) AWC is equal to the difference between moisture content at field capacity and at wilting point.

(2) P is sum of the average values of permeability for each layer of soil weighted by the thickness of the layer, summed over the entire basin.

(3) P_A is the average permeability for the upper layer soil weighted by percent of soil type in basin, summed over the basin.

possibilities which appear to be hydrologically feasible. The following several relations were found which are of interest to this Model. (a) The lower zone soil moisture storage capacity was related to AWC. (b) Rate of infiltration index was related to P_A. (c) Index to rate of evapotranspiration was related to overland slope and forest cover. (d) Index to upper zone moisture storage capacity was related to overland slope, forest cover and P_A.

In assessing Ross's approach, it may be said that the overall approach is sound. It can be argued that more investigation could have been made into parameter sensitivity and interaction. However, these were at least considered. This study benefits from the examples of basin characteristics data used in developing the relationships and from the form of the relationships developed for analagous parameters. It is felt that there are three areas of concern which future studies should avoid. These include (a) a thorough examination of parameter stability prior to determining parameter values by averaging values determined over several time periods, (b) the use of a larger data base in developing the relationships, and (c) the use of split sampling methods to verify the relationship on basins withheld from the correlation.

Ambaruch and Simmons Study

The objective of this study was to develop a method of relating the physical characteristics of basins as found by remote sensing means to the parameters of conceptual rainfall-runoff model in order that there could be a reduction in "time and expense normally involved in achieving the ability to predict the hydrological behavior of an ungaged watershed". This is, in reality, an extension of the James et al. study as both OPSET and KWM are used with the same approach as outlined by Ross. While it is stated that the study needed 50 stations, 35 for developing relationships and 15 for verification, only 15 stations in the Tennessee River Valley (stations in states of Tennessee, North Carolina, and Alabama) were used (10 for developing the relationships, and 5 for verification). The determination of the optimal parameter values was done as explained above for Ross (1970). They did study parameter sensitivity and "fine tune" some parameter values. The collection of basin characteristics data was, also, along the same line as Ross (1970). While the name of the study implied sophisticated imagery data, this was not the case; air photography and topo maps were primary sources of data augmented by soils data.

The approach to the correlations was slightly different in determining which possibility should be considered. Ambaruch attempted correlations with various sets of a model parameter and several physical characteristics. This was also augmented by hydrologic subjectivity. The resulting correlations using only 10 stations, which are of interest to this study, are as follows: (a) index to infiltration rate was related to P_A: (b) a seasonal adjusting factor for infiltration rate was related to percent impervious area, AWC, overland flow surface slope and overland flow surface length; (c) lower zone capacity was related to overland flow slope, AWC and P_A;

(d) index to evapotranspiration loss was related to the overland flow surface value of Manning's n; (e) index to upper zone capacity was related to Manning's n for overland flow surface, and overland flow surface length; (f) seasonal adjusting factor for upper zone storage was related to fraction impervious area, and AWC; (g) a channel storage routing coefficient was related to Manning's n for impervious areas of the overland flow surface and AWC; and (h) a flood plain storage routing coefficient was related to P_A and overland surface length.

In assessing this approach, the same statements as applied to Ross apply. The fact that only 10 stations were used to develop these relationships means that little actual application could come from the study until more stations are involved. The use of the five verification stations was a proper approach to take.

Maggette, Shanholtz and Carr Study

This study was viewed as an extension of the previous two studies, Ross (1970) and Ambaruch and Simmons (1973). OPSET was used to determine the six nonmeasurable parameters for KWM at 21 watersheds in the states of Virginia, North Carolina, South Carolina, and Tennessee. Simple linear equations were attempted but found to be unsatisfactory. Multiple linear equations were determined by using fifteen watershed characteristics as independent variables or their combinations. These were added to the equations in a stepwise manner according to which had the highest partial correlation with the dependent variable. No more than six independent variables were allowed in a particular equation.

The fifteen independent variables selected consisted of A, drainage area, P, drainage basin perimeter, CC, ratio of perimeter to that of a circle of equal area (compactness coefficient), DD, drainage density, FF, shape factor as defined in Ross (1970), S_{mc}, average slope of main channel, R_{max}, maximum relief, S, average watershed slope, RR, ratio of maximum relief to axial length of watershed (relief ratio), W, percent of wooded area, L_a, axial length, D, depth to impervious layer, OFSS, overland flow surface slope, P_A, average permability of A horizon and, L_c, total length of identifiable channels. The authors allowed multiple interactions of these variables to enter the regressions. They also defined some parameters as a function of another parameter and some independent variables.

The results obtained are summarized as follows: (a) index of depression storage was related to the parameter indexing infiltration rate and the variable, W, and the two variable interactions produced by multiplying CC by DD and FF by W; (b) index to seasonal variation in depression storage was related to FF, S_{mc}, R_{max}, RR, L_c, and OFSS; (c) index of watershed soil moisture storage capacity was related to the parameter indexing infiltration rate, the four variables, A, P, L_c and L_a, and the interaction produced by multiplying S_{mc} by L_c; (d) index of soil moisture loss rate through evaporation is related to the four variables CC, L_c, S and D and the two interactions produced by multiplying S by the parameter indexing soil moisture storage capacity and by multiplying P_A by D; (e) index of seasonal variation in infiltration rate was related to the four variables, A, CC, L_c and D and two interactions produced by multiplying D by the parameter indexing soil moisture storage capacity, and by multipying CC by D; (f) index of watershed infiltration rate was related to FF, S_{mc}, P_A, L_c, S and L_A. Five sites were used to test these resulting equations.

In assessing this approach by Maggette et al., three comments seem necessary. First, the approach is acceptable in that it is founded on the two previous studies. Second, the use of multiple linear regression and stepwise addition of variables appears to be an approach necessary for developing relationships for a large number of drainage basins. Finally, the inclusion of predicted parameters and variable interactions into the equations appears to be a method which should be approached with caution. While the inclusion of predicted parameters appears to be justified, the interactions between not only variables but also variable and predicted parameter may allow spurious correlation to enter the equation development.

Johnston and Pilgrim Study

This study was intended to determine relationships for the parameters of the Boughton Model to basin characteristics. The chief concerns were to determine truly optimum parameter values. Upon discovering the difficulties in deciding whether a parameter was truly optimal or not, and considering their data base to be insufficient, this study was then directed towards the study of parameter optimization. It is included here to reemphasize that the difficulty in determining relationships between a parameter value and basin characteristics resides with the parameter optimization process. As this study has been summarized previously with respect to the fitting process, only some pertinent recommendations are given here which they felt would increase the effiicency of the optimization. These were as follows: (a) Use of long records of "good" data, with the use of split-sampling. (b) Try several different starting parameter value sets. (c) Use a "dual" search technique.

Summary

The studies of James et al., Ambaruch and Simmons, Maggette, Shanholtz and Carr, and Johnston and Pilgrim offer some valuable lessons to be applied to this research. The first three indicate (a) possible required basin characteristics, (b) usable relations determined from soils data, (c) hints at possible feasible relationships, (d) the need for sufficient data bases, and (e) the need to adequately verify the determined relationships. While Johnston and Pilgrim mention some of these points also, the value of their study is the emphasis placed on thoroughly analyzing the optimization process so that parameters values produced will be acceptable.

Summary of Literature Review

The intent of this chapter was to review the literature for information which would be of use to this research. Such information is classified under the two headings, "Determination of the physical significance of model parameter values" and "Previous attempts at relating the parameter values of conceptual rainfall-runoff models to basin characteristics".

Information under the first heading is summarized as follows.

The U.S.G.S. Model is considered consistent with respect to other conceptual lumped parametric rainfall-runoff models, the hydrologic theory used and the response produced. This allows consideration of the physical significance of the Model parameters. However, it must be realized that the Model is subject to change to encompass "better" theoretical guidelines. The Model adequacy must also be qualified in that the lumped nature of the parameters and input will affect the physical significance of the Model output. The determination of the parameter values must not only be considered in this context but should be determined with attention given to their sensitivity and interdependencies. Previously untried fitting techniques and objective function forms will be studied to evaluate the applied optimization process. The effects of data errors will be controlled by choosing sufficiently long records representing enough events and moisture conditions. The data records will be screened to improve quality. It is hoped that these steps will aid in determining physically significant parameters.

Information under the second heading is summarized as follows. The derivation of relationships between the parameters of this Model and basin characteristics will be done with a sufficient number of basins. Verification of the relationships will be done on an adequate scale. The attention paid to the optimization process should result in relatively more physically signigicant parameter values used in establishing these relationships. Thus, it is hoped that these relationships will produce physically significant parameters to be used with the Model.

CHAPTER IV

PARAMETER SENSITIVITY AND SIGNIFICANCE

Introduction

The input and the parameters of a hydrologic model determine the output of that model. The manner in which the output varys for a given input when a parameter changes defines the sensitivity of that particular parameter and, in a practical sense, its significance to the model operation. This chapter defines the sensitivity of the ten parameters used with the U.S.G.S. Model, redefined in Table 2, and establishes the significance of these parameters. The information obtained is applied to this study as a means of deciding whether or not a parameter value is acceptable for the purpose of developing a relationship between the parameter and physical basin characteristics.

Details of the procedure followed are given in the remaining sections of this chapter. The first explains the process applied in selecting suitable test sites for studying parameter sensitivity. The second explains the definition of parameter sensitivity as applied in this study, the specific forms and testing procedures used to measure parameter sensitivity and the results of the findings. The third section analyzes these results and the final one presents the conclusions drawn pertinent to this study.

Selection of Test Sites

The six state study area contained 344 drainage basin sites with

Table 2. The Ten Parameters of the U.S.G.S. Rainfall-Runoff Model

Parameter Identifier		Units	Definition
(1)	PSP	inches	Minimum value of the effect of capillary suction and the soil moisture differential at the boundary between the two layers of the soil column. It occurs when soil moisture is at field capacity.
(2)	RGF	- - -	Ratio of capillary suction at wilting point conditions to that at field capacity.
(3)	KSAT	inches per hour	Value of saturated hydraulic conductivity used to determine infiltration rates.
(4)	DRN	- - -	Represents a constant drainage rate for redistributing moisture from surface moisture storage to base moisture storage. It is inputted as a proportion of KSAT.
(5)	BMSM	inches	Soil moisture storage volume at field capacity.
(6)	RR	- - -	Proportion of daily rainfall that infiltrates the soil.
(7)	EVC	- - -	Coefficient to convert pan evaporation to potential evapotranspiration values.
(8)	KSW	hours	Constant time coefficient for linear reservoir routing.
(9)	TC	minutes	Duration of the triangular translation hydrograph.
(10)	TP/TC	- - -	Ratio of the time to peak of the Triangular translation hydrograph to its duration.

previous calibrations for the Model. Assuming that the infiltration and routing components were indeed the most critical parts of the Model, equations involving several parameters used in these components were defined to select a sample of available sites to determine parameter sensitivity. Three relationships were used. Two used parameters associated with the infiltration component, and the other used ones from the routing component.

The two relationships for the infiltration component are apparent upon considering the results of substituting equation (II.6) into equation (II.5). This yields

$$FR = KSAT \ (1 + \frac{PSP}{SMS} \ (RGF - [(RGF - 1) \ \frac{BMS}{BMSM}])) \tag{IV.1}$$

where FR is the infiltration rate, KSAT, PSP, RGF and BMSM are the Model parameters as defined in Table 2, SMS is the current value of surface moisture storage and BMS is the current value of base moisture storage. Defining wet moisture conditions as when BMS equals BMSM, an infiltration rate for wet conditions, FR_{wet}, can be expressed as

$$FR_{wet} = KSAT \ [1 + \frac{PSP}{SMS}]. \tag{IV.2}$$

This can be expressed as

$$FR_{wet} = KSAT + \frac{KSAT \times PSP}{SMS}. \tag{IV.3}$$

This leads to the form for the first relationship, FRWET, defined as

$$FRWET = KSAT \times PSP \tag{IV.4}$$

In a similar manner, the second relationship can be defined. Defining dry moisture conditions as when BMS equal 0.0, an infiltration rate for dry conditions, FR_{dry}, can be expressed as

$$FR_{dry} = KSAT \; [1 + \frac{PSP \times RGF}{SMS}]. \tag{IV.5}$$

This can be expressed as

$$FR_{dry} = KSAT + \frac{KSAT \times PSP \times RGF}{SMS}. \tag{IV.6}$$

This leads to the form of the second relationship, FRDRY, defined as

$$FRDRY = KSAT \times PSP \times RGF. \tag{IV.7}$$

The third relationship chosen represents parameters associated with the routing component. Applying the definition of basin lag time as time from centroid of rainfall excess to centroid of direct runoff, O'Kelly (1955) shows that basin lag time is equal to one-half the base of an isosceles triangle translation hydrograph plus the linear storage constant. Expressing this in terms of Model parameters, this becomes

$$LAG = KSW + \frac{1}{120}\, TC \tag{IV.8}$$

where LAG is in hours and KSW and TC are as defined in Table 2.

The test sites were then selected using the following procedure. The values for FRWET, equation (IV.4), FRDRY, equation (IV.7) and LAG, equation (IV.8), were computed for all sites available. The maximum, minimum, mean and standard deviation were computed for each of these. A site was selected if its value for FRWET, FRDRY or LAG equaled the maximum or minimum. A site was selected if its value for FRWET, FRDRY or LAG was within one standard deviation of the mean. These sites were limited to three per each relationship according to proximity to mean. Table 3 shows the values for the three relationships and sites chosen from this procedure. Several of these sites (02443605), 02447220, 03431700, 03597500, 04089500, and 07068200) were unavailable for use as test sites due to data problems. Two more sites, 07011500 (FRWET = 0.111, FRDRY = 1.32, LAG = 0.759) and 02410000 (FRWET = .930, FRDRY = 10.32, LAG = 2.134) were selected as representative of the range of parameters. Table 4 presents a complete list of the final selection of test sites, locations and parameter values used in defining parameter sensitivity.

The purpose of this selection process was to ensure that parameter values available for sensitivity studies were in the range of values determined for all the sites available. It was assumed that if the ranges of parameter values for the selected test sites approximated those of the total sites available that this qualification was met. Table 5 shows a comparison between the selected test sites and total available sites with respect to the minimum and maximum values

Table 3. Study Area Station Numbers Corresponding to Minimum, Mean and Maximum Values for FRWET, FRDRY and LAG

RELATIONSHIP	MINIMUM		MEAN		MAXIMUM	
	Value	Sta. No. at Value	Value ±(std. dev.)	Sta. No. Nearest Mean	Value	Sta. No. at Value
(1) FRWET	0.0049	02435300	0.2134 ±(0.266)	02191600 03431700 05495100	1.81	06909700
(2) FRDRY	0.0099 0.0202*	02435300 02443605	2.805 ±(3.65)	02192400 03431670 05555400	27.81	07068200
(3) LAG	0.222	05558050	3.271 ±(3.32)	02447220 02488540 03597500	29.99	04089500

*Indicates value for 2nd. lowest.

Table 4. List of Selected Test Sites and Parameter Values

Station Number	State	Station Name	DA, Sq. Mi.	PSP, IN.	KSAT, IN/HR	DRN	RGF	BMSM IN.	EVC	RR	KSW, HRS.	TC, MIN.	TP/TC
02191600	Georgia	Double Branch nr. Danielsville, GA	4.77	1.45	0.147	0.21	13.5	4.10	0.78	0.98	2.06	211	0.50
02192400	Georgia	Anderson Mill Creek nr. Danburg, GA	5.49	2.62	.056	.10	17.6	3.15	.68	.99	3.37	234	.50
02410000	Alabama	Paterson Creek nr. Central, AL	4.95	7.75	.120	.34	11.1	8.78	.84	.91	1.01	135	.52
02435300	Mississippi	Cow Pike Pass nr. Tupelo, MS	0.14	0.41	.012	1.00	2.01	1.82	.70	.80	0.54	44.6	.50
02488540	Mississippi	New Hebron Gulley at New Hebron, MS	2.50	3.87	.025	1.00	11.1	3.52	.70	.80	1.83	159	.50
03431670	Tennessee	Richland Creek at Dunham Springs, TN	12.40	3.27	.087	0.35	10.0	6.95	.85	.90	0.70	135	.50
05495100	Missouri	Big Branch Trib. nr. Wayland, MO	0.70	4.17	.051	.63	16.6	4.73	.70	.84	1.22	87.5	.51
05555400	Illinois	Vermilion River Trib. at Lowell, IL	.14	1.91	.129	1.00	11.8	2.91	.97	.90	0.31	17.2	.50
05558050	Illinois	Coffee Creek Trib. nr Florid, IL	.03	2.78	.102	1.00	11.3	1.77	.50	.90	.080	17.0	.50
06909700	Missouri	Petite Saline Crk. Trib. nr. Bellair, MO	.49	8.64	.210	0.76	4.43	3.40	.72	.90	.60	49.0	.84
07011500	Missouri	Green Acre Branch nr. Rolla, MO	.62	2.22	.050	.33	11.9	3.93	.77	.87	.49	32.3	.97

Table 5. Comparison of Parameter Value Minimum and Maximum between All Selected Test Sites and All Sites Available

MODEL PARAMETER	MINIMUM		MAXIMUM	
	All Selected Test Sites	All Sites Available	All Selected Test Sites	All Sites Available
PSP	0.41	0.17	8.64	21.2
KSW	.012	.010	0.210	0.218
DRN	.10	.050	1.00	1.00
RGF	2.01	1.94	17.6	58.3
BMSM	1.77	0.54	8.78	37.8
EVC	0.50	.30	0.97	1.06
RR	.80	.51	.99	1.46
KSW	.080	.080	3.37	20.8
TC	17	11	234	1100
TP/TC	0.50	0.18	0.97	1.00

for each parameter. This table shows that four of these parameters, KSW, DRN, EVC, and TP/TC, approximate both the maximum and minimum and are considered to adequately represent the range in values for those four parameters. Four of the parameters, RGF, BMSM, KSW and TC, have minimum values which adequately approximate the minimums for all available sites, but their maximum values differ from the maximums for all available sites by a factor greater than three. However, inspection of the parameter values available showed that the maximum values for these four parameters were sufficiently high to be greater than the actual corresponding parameter value for 85-90% of the total sites available. For this reason, the range of each of these four values was also considered to be adequately represented. Two parameters, PSP and RR, are within a factor of three of their bounds. They are considered to adequately represent the range as the maximum value for PSP, 8.64, and its minimum value are adequate for 98% of the total sites available and the maximum value for RR, 0.99, and its minimum value, .80, are adequate for 90% of the total sites available.

Parameter Sensitivity

In general, parameter sensitivity can be defined as a measure of the change in output when a parameter value has been varied given all other parameters and inputs have remained the same. This study has used a measure of sensitivity called relative sensitivity, RS, and defined it as the ratio of the relative change in output to the relative change in the parameter value. This is written as

$$RS = \frac{\frac{\Delta O}{O}}{\frac{\Delta P}{P}} \qquad \text{(IV.9)}$$

where ΔO is the change in model output, 0 is the output at the optimum parameter values, ΔP is the change in parameter value, and P is the optimum parameter value.

Application of this measure makes it possible to make comparisons not only between different parameters but also between different sites. The choice of output for the Model is storm event output such as the peak discharge, runoff volume, and moisture storage values. This allows the determination of parameter sensitivity over these various outputs for different type storm events. Comparisons of relative sensitivity between parameters, outputs and events is used to show which parameters are affecting model response. This information is valuable in determining which parameters may be considered for defining relationships between the parameter and basin characteristics.

The procedure for determining relative sensitivities for these 11 test sites relied on obtaining the output for storm events by incrementing each of the ten parameters separately up to a maximum value of not less than 2.0 times the calibrated value, and down to a minimum value of not more than 0.20 times the calibrated value, and applying each incremented parameter to the Model given all other parameters remain at the calibrated value and there is no change in input to the Model. This information of incremented parameter values and corresponding storm event output was then used to compute relative sensitivities for each storm event by applying equation (IV.9) to several points about the optimum or calibrated parameter value and averaging the results. The incremented values of the parameters were not restricted to a reasonable upper bound. Consequently, an interpretation of the results of analyzing the relative sensitivities includes consideration of the validity of these upper bounds. The output data produced from incrementing the parameters is also presented in plot form in Appendix C. Figures C.1 through C.9 serve as a visual study. The results shown are typical of the plots for any event at any of the test sites except for actual values. The plots show that for a storm event peak and runoff volume seven of the ten parameters PSP, KSAT, DRN, RGF, EVC, KSW and TC, are negatively sensitive in that an increase in the parameter value results in a decrease in the output value, two, RR and TP/TC, are positively sensitive and one, BMSM, exhibits alternating sensitivity, i.e., both negative and positive sensitivity.

While the plots serve as a good indicator of parameter sensitivity, only the quantitative value of relative sensitivity was subject to detailed analysis for the linearly sensitive parameters, PSP, KSAT, RGF, DRN, EVC, RR, KSW, TC and TP/TC. There were a total of 189 storm events available for the 11 test sites. In order to determine parameter sensitivity over various storm event types, these storms were classified according to (1) seasons of the year, (2) ratio of storm runoff, RØ, to storm rainfall, RF, (3) ratio of storm peak discharge, Q, to drainage area, DA, (4) average daily rainfall for storm event, AVE PRECIP, (5) an antecedent mositure index, AMI[1/], and (6) a 3-hour storm intensity factor, SIF-3HR[2/]. In order to make evaluations of sensitivity within these classes, all except seasons of the year were separated into three levels of relative magnitude, designated LOW, MEDIUM and HIGH. The bounds for these levels were determined from the 33rd-percentile and 67th-percentile limits for these classes. These bounds are given in Table 6. The number of storm events for these classes and levels within them are given for each test site in Table 7. The relative sensitivities for the parameters were ranked for each storm event. The mean value of relative sensitivity for each parameter

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[1/] Antecedent moisture index, AMI, was defined as being equal to the 10-day antecedent precipitation index given by Linsley, Kohler, Paulhus, 1975. Thus, AMI was computed by the following equation,

$$AMI = \sum_{i=1}^{10} P_i * K^i$$

where K was chosen equal to 0.90, and P_i was equal to daily rainfall for the i-th day.

[2/] Storm intensity factor is defined as the storm's maximum total rainfall over a selected time period. Values were computed for time periods of 15-minutes, 1-hour and 3-hours. As expected all three values were highly correlated, 3-hours was chosen due to a higher correlation with storm precipitation.

Table 6. Class Division Bounds for Separation of Storm Event Types

CLASS ID	BOUNDARIES		
	Low	Medium	High
Ratio of storm runoff volume to storm rainfall amount, RO/RF	≤ = 0.25	0.25 < RO/RF ≤ 0.45	0.45 < RO/RF ≤ 1.0
Ratio of storm peak discharge to drainage area, Q/DA	≤ = 75.0	75.0 < Q/DA ≤ 250.0	> 250.0
Average daily rainfall for storm event, AVE STORM PRECIP	≤ = 1.25	1.25 < ASP ≤ 2.00	> 2.00
Antecedent moisture index, AMI	≤ = 0.50	0.50 < AMI ≤ 1.25	1.25 < AMI < 51.0*
3-hour storm intensity factor, SIF-3HR	0 < SIF ≤ 1.20**	1.20 < SIF ≤ 1.80	> 1.80

* AMI > 50.0 denotes missing data.
** SIF-3HR = 0 denotes missing data.

Table 7. Number of Storms per Class Division at Each Test Site

Class Level	02191600	02192400	02410000	02435300	02488540	03431670	05495100	05555400	05558050	06909700	07011500	Total
TOTAL:	18	26	27	6	18	21	16	7	20	15	18	189
SEASON:												
FALL	5	2	6	0	2	8	1	0	2	2	3	31
WINTER	6	14	7	3	2	6	2	0	1	0	1	42
SPRING	5	8	10	2	9	5	3	5	10	10	7	74
SUMMER	2	2	4	1	5	2	10	2	7	3	4	42
RO/RF:												
LOW	8	10	13	0	8	6	7	4	4	5	1	66
MED	7	11	12	0	7	12	4	1	6	7	8	75
HIGH	3	5	2	6	3	3	5	2	10	3	6	48
Q/DA:												
LOW	10	16	12	0	13	10	3	1	0	0	0	65
MED	6	10	14	0	3	11	10	5	0	3	4	67
HIGH	2	0	1	6	2	0	3	1	20	12	11	58
AVE PRECIP:												
LOW	8	13	8	3	6	15	6	4	9	3	8	84
MED	3	12	9	2	9	5	8	2	7	6	4	65
HIGH	7	1	10	1	3	1	2	1	4	6	3	40

Table 7. continued

Class Level	02191600	02192400	02410000	02435300	02488540	03431670	05495100	05555400	05558050	06909700	07011500	Total
AMI:												
LOW	3*	6*	10	4	7	4	2	4	3	5	5	53
MED	5	11	9	1	7	13	8	3	9	2	4	72
HIGH	5	4	8	1	4	4	6	0	8	8	6	54
SIF-3HR:												
LOW	4*	9*	3	3	8	16	8	4	5	1	6	67
MED	4	8	9	3	5	5	4	2	8	4	5	57
HIGH	5	7	15	0	5	0	4	1	7	10	4	55

* Data problems reduced number of storms at this site for this storm event class.

and Kendall's coefficient of concordance, W,[3/] was then computed for the test sites both as a group and individually, and for the various divisions of the storm event type classes.

For this analysis of sensitivity, storm event model output was considered to be peak discharge, runoff volume, and the mositure storage values as represented by base moisture storage on the day previous to the storm event (representing antecedent conditions), BMS MINUS, the storm average values for both surface moisture storage, SMS, and base moisture storage, BMS, and the value for base moisture storage following the storm, BMS PLUS. Tables 8, 9, 10a, 10b, 10c and 10d present the mean relative sensitivity values for the parameters

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[3/] The computation of Kendall's coefficient of concordance, W, is a method of deciding whether or not the rankings of n individuals by m observers are substantially in agreement with each other. The coefficient of concordance, W, is defined by

$$W = \frac{12S}{m^2(n^3 - n)}$$

where S equals the sum of squares of the deviations of the total of the ranks assigned to each parameter from the mean of the totals of the ranks, n is the number of individuals or, for this study, parameters to be ranked and m is the number of observers or, for this study, number of storm events.

W varies from 0 to 1 with 0 denoting no agreement and 1 representing perfect agreement. The null hypothesis that there is no agreement may be tested by calculating, $X^2 = m(n - 1)W$, which is distributed as chi-square with n - 1 degrees of freedom. If X^2 exceeds the chi-square table value then the null hypothesis can be rejected and the rankings may be assumed to agree. If this happens, then an estimate of the true ranking may be made by assigning the lowest rank to individual with lowest sum of ranks and etc. (Ostle, 1966).

Table 8. Mean Relative Sensitivities for Peak Discharges

CATEGORY	NUMBER STORM EVENTS	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	$^{TP}/_{TC}$
TEST SITES:											
All Sites	189	-0.709	-0.847	-0.077	-0.523	0.018	-0.715	0.533	-0.476	-0.281	0.040
02191600	18	- .615	- .791	- .026	- .451	- .018	- .682	.571	- .444	- .263	.025
02192400	26	- .678	- .758	- .005	- .535	.272	- .782	.527	- .567	- .220	.033
02410000	11	-1.118	-1.301	- .071	- .894	- .198	-1.260	.896	- .376	- .340	.051
02410000	16	-0.904	-1.270	- .264	- .529	.060	-0.809	.583	- .380	- .306	.029
02435300	6	- .051	-0.028	0.0	- .025	.0077	- .016	.013	- .527	- .198	.025
02488540	18	- .598	- .643	- .031	- .547	.028	- .514	.229	- .617	- .332	.065
03431670	21	- .966	-1.145	- .085	- .641	- .140	-1.036	.909	- .299	- .404	.051
05495100	16	- .811	-1.036	- .194	- .643	- .218	-1.150	1.132	- .649	- .282	.056
05555400	7	-1.134	-1.312	- .127	-1.096	- .094	-0.974	0.255	- .621	- .179	.024
05558050	20	-0.530	-0.586	- .039	-0.376	.128	- .439	.294	- .234	- .313	.026
06909700	15	- .769	- .862	- .050	- .422	.050	- .407	.227	- .560	- .244	.045
07011500	15	- .276	- .349	- .076	- .215	- .011	- .308	.343	- .577	- .176	.025
SEASONS:											
FALL	35	-0.780	-0.905	-0.051	-0.583	-0.179	-0.636	0.560	-0.359	-0.271	0.035
WINTER	45	- .585	- .746	- .067	- .332	.083	- .547	.537	- .432	- .250	.035
SPRING	85	- .631	- .756	- .081	- .472	.099	- .653	.400	- .422	- .239	.035
SUMMER	47	- .567	- .649	- .062	- .496	- .051	- .697	.490	- .470	- .256	.038
RO/RF:											
LOW	81	-0.763	-0.870	-0.057	-0.666	0.00755	-0.816	0.484	-0.407	-0.242	0.037
MED	79	- .608	- .742	- .065	- .386	.034	- .614	.520	- .440	- .265	.037
HIGH	47	- .467	- .582	- .085	- .265	.043	- .409	.360	- .428	- .243	.032
Q/DA:											
LOW	77	-0.820	-0.993	-0.082	-0.627	0.040	-0.897	0.592	-0.416	-0.258	0.041
MED	73	- .627	- .754	- .074	- .479	- .044	- .634	.539	- .434	- .255	.035
HIGH	62	- .404	- .460	- .047	- .251	.058	- .321	.256	- .423	- .236	.028
AVE PRECIP:											
LOW	90	-0.801	-0.985	-0.101	-0.556	0.052	-0.815	0.582	-0.440	-0.274	0.041
MED	73	- .582	- .670	- .053	- .449	- .0067	- .571	.472	- .474	- .263	.040
HIGH	49	- .395	- .457	- .033	- .326	- .014	- .413	.284	- .323	- .189	.019
AMI:											
LOW	56	-0.755	-0.834	-0.030	-0.632	0.115	-0.675	0.362	-0.464	-0.250	0.036
MED	80	- .655	- .782	- .081	- .507	- .024	- .727	.570	- .422	- .274	.038
HIGH	66	- .455	- .603	- .096	- .227	- .027	- .428	.415	- .384	- .220	.033
SIF 3HR:											
LOW	75	-0.744	-0.924	-0.100	-0.510	-0.021	-0.747	0.623	-0.430	-0.264	0.039
MED	66	- .573	- .664	- .061	- .407	- .088	- .561	.389	- .422	- .260	.039
HIGH	61	- .509	- .589	- .049	- .424	- .025	- .511	.342	- .410	- .228	.029

Table 9. Mean Relative Sensitivities for Storm Runoff Volumes

CATEGORY	NUMBER STORM EVENTS	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:									
All Sites	145	- .825	-1.016	-.093	-.551	.048	- .766	.571	0
02191600	18	- .723	- .960	-.027	-.520	.011	- .707	.605	0
02192400	26	- .766	- .864	-.006	-.584	.294	- .861	.562	0
02410000	27	-1.065	-1.416	-.217	-.708	-.050	-1.018	.768	0
02435300	6	- .055	- .050	-.005	-.027	.008	- .021	.017	0
03431670	18	-1.397	-1.647	-.071	-.931	-.163	-1.371	1.030	0
05558050	20	- .657	- .765	-.083	-.422	.149	- .540	.352	0
06909700	15	- .884	-1.039	-.096	-.423	.078	- .412	.233	0
07011500	15	- .404	- .569	-.176	-.305	-.051	- .445	.492	0
SEASONS:									
FALL	27	-1.080	-1.286	-.070	-.772	-.234	- .998	.750	0
WINTER	36	- .727	- .926	-.070	-.381	.119	- .645	.589	0
SPRING	57	- .785	- .990	-.127	-.504	.150	- .702	.487	0
SUMMER	25	- .781	- .915	-.076	-.667	.020	- .836	.543	0
RO/RF:									
LOW	46	-1.109	-1.292	-.068	-.911	.089	-1.088	.683	0
MED	63	- .787	-1.002	-.108	-.453	.030	- .731	.613	0
HIGH	33	- .568	- .740	-.109	-.284	.030	- .440	.375	0
Q/DA:									
LOW	47	-1.204	-1.497	-.103	-.865	.066	-1.192	.816	0
MED	46	- .744	- .914	-.082	-.499	-.005	- .734	.612	0
HIGH	52	- .554	- .672	-.095	-.315	.079	- .409	.313	0
AVE PRECIP:									
LOW	65	- .946	-1.196	-.122	-.570	.088	- .806	.619	0
MED	49	- .762	- .907	-.069	-.543	.037	- .762	.576	0
HIGH	31	- .671	- .811	-.072	-.527	-.020	- .869	.463	0
AMI:									
LOW	40	- .938	-1.089	-.053	-.725	.086	- .886	.491	0
MED	52	- .829	- .994	-.875	-.565	.507	- .792	.633	0
HIGH	43	- .665	- .920	-.159	-.302	-.004	- .534	.516	0
SIF 3HR:									
LOW	46	- .947	-1.221	-.128	-.564	-.030	- .843	.710	0
MED	47	- .754	- .911	-.094	-.469	.137	- .664	.488	0
HIGH	42	- .718	- .853	-.076	-.557	.020	- .705	.455	0

Table 10a. Mean Relative Sensitivities for BMS Value on Day Previous to Storm

CATEGORY	NUMBER STORM EVENTS	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:									
All Sites	145	0.015	0.022	0.0001	0.013	1.168	-1.108	1.018	0
02191600	18	.038	.046	- .0006	.034	1.059	-1.067	1.071	0
02192400	26	.0007	.0010	0.	0.	1.502	-1.414	0.923	0
02410000	27	.025	.034	- .008	.021	1.006	-1.204	.870	0
02435300	6	0.	0.	0.	0.	1.450	-2.459	1.404	0
03431670	18	.010	.014	.0005	.008	0.918	-0.498	1.434	0
05558050	20	.007	.010	0.	.006	1.342	- .345	1.023	0
06909700	15	.026	.030	- .007	.022	1.288	- .781	0.544	0
07011500	15	.009	.033	.022	.006	0.850	-1.677	1.203	0
SEASONS:									
FALL	27	0.017	0.035	0.014	0.015	0.716	-0.849	1.224	0
WINTER	36	.032	.024	- .003	.002	1.042	- .494	0.604	0
SPRING	57	.018	.031	.004	.015	1.435	-1.281	.920	0
SUMMER	25	.024	.013	- .020	.023	1.230	-1.690	1.616	0
RO/RF:									
LOW	46	0.025	0.044	0.008	0.022	1.231	-1.847	1.266	0
MED	63	.013	- .0005	- .020	.010	1.154	-0.462	0.902	0
HIGH	33	.004	.031	.028	.003	1.116	- .923	.804	0
Q/DA:									
LOW	47	0.021	0.031	-0.001	0.019	1.087	-1.046	1.142	0
MED	46	.011	.023	.008	.008	1.179	-1.310	0.966	0
HIGH	52	.014	.013	- .006	.012	1.233	-0.895	.953	0
AVE PRECIP:									
LOW	65	0.014	0.050	0.031	0.013	1.115	-1.124	0.845	0
MED	49	.015	.008	- .011	.013	1.157	-0.935	1.041	0
HIGH	31	.018	- .016	- .048	.013	1.299	-1.197	1.346	0
AMI:									
LOW	40	0.011	-0.030	-0.046	0.009	1.318	-1.665	1.270	0
MED	52	.012	.020	.0010	.009	1.234	-0.990	1.139	0
HIGH	43	.027	.077	.042	.024	.993	- .611	0.612	0
SIF 3HR:									
LOW	46	0.005	0.040	0.030	0.003	0.956	-0.774	1.016	0
MED	47	.010	.010	- .007	.008	1.170	- .644	0.916	0
HIGH	42	.036	.020	- .025	.032	1.444	-1.869	1.109	0

Table 10b. Mean Relative Sensitivities for Storm Average SMS

CATEGORY	NUMBER STORM SITES	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:									
All Sites	145	0.381	-0.199	-0.741	0.236	-0.058	0.302	-0.333	0
02191600	18	.442	- .227	- .596	.308	.058	.388	- .554	0
02192400	26	.300	.270	- .068	.215	- .143	.303	- .242	0
02410000	27	.361	- .576	-1.095	.201	- .036	.314	- .257	0
02435300	6	.324	- .189	-0.367	.200	- .036	.016	- .108	0
03431670	18	.485	- .419	-1.146	.274	- .161	.250	- .698	0
05558050	20	.291	- .036	-0.510	.182	- .058	.294	- .285	0
06909700	15	.390	- .402	-1.297	.196	- .060	.233	- .184	0
07011500	15	.493	- .327	-0.859	.336	.026	.428	- .227	0
SEASONS:									
FALL	27	0.462	-0.522	-1.143	0.256	0.155	0.390	-0.436	0
WINTER	36	.338	- .057	-0.478	.166	- .099	.240	- .306	0
SPRING	57	.386	- .190	- .815	.254	- .147	.295	- .347	0
SUMMER	25	.345	- .074	- .517	.278	- .030	.309	- .228	0
RO/RF:									
LOW	46	0.321	-0.149	-0.573	0.262	-0.0004	0.264	-0.263	0
MED	63	.415	- .173	- .804	.239	- .128	.344	- .416	0
HIGH	33	.381	- .312	- .840	.186	- .014	.269	- .257	0
Q/DA:									
LOW	47	0.322	-0.291	-0.733	0.210	-0.008	0.261	-0.262	0
MED	46	.430	- .067	- .657	.267	- .132	.329	- .481	0
HIGH	52	.391	- .232	- .822	.234	- .039	.314	- .266	0
AVE PRECIP:									
LOW	65	0.386	-0.379	-0.938	0.216	-0.093	0.248	-0.320	0
MED	49	.324	.023	- .442	.206	- .055	.269	- .295	0
HIGH	31	.462	- .172	- .800	.328	.009	.465	- .420	0
AMI:									
LOW	40	0.366	-0.216	-0.661	0.251	-0.063	0.279	-0.250	0
MED	52	.345	- .041	- .518	.234	- .079	.331	- .363	0
HIGH	43	.436	- .421	-1.158	.206	- .077	.268	- .333	0
SIF 3HR:									
LOW	46	0.310	-0.285	-0.717	0.182	-0.013	0.211	-0.167	0
MED	47	.393	- .247	- .808	.198	- .106	.277	- .447	0
HIGH	42	.443	- .100	- .766	.319	- .104	.410	- .345	0

Table 10c. Mean Relative Sensitivities for Storm Average BMS

CATEGORY	NUMBER STORM EVENTS	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:									
All Sites	145	0.025	0.109	0.087	0.019	1.068	-1.002	0.720	0
02191600	18	.034	.184	.145	.029	0.847	-0.596	.675	0
02410000	27	.024	.196	.158	.020	.938	-1.278	.806	0
02192400	26	.0007	.064	.063	0.	1.433	-1.292	.836	0
02435300	6	.027	.140	.110	.017	1.371	-2.187	1.191	0
03431670	18	.013	.115	.101	.009	0.846	-1.205	1.075	0
05558050	20	.042	.112	.091	.035	.985	-0.196	0.173	0
06909700	15	.057	.112	.079	.041	1.046	- .225	.163	0
07011500	15	.013	- .081	- .094	.007	1.207	-1.626	1.090	0
SEASONS:									
FALL	27	0.019	0.192	0.173	0.015	0.681	-1.230	0.904	0
WINTER	36	.004	.050	.043	.002	1.012	-0.434	.527	0
SPRING	57	.033	.119	.089	.024	1.248	- .890	.633	0
SUMMER	25	.041	.085	.051	.036	1.153	-1.829	.998	0
RO/RF:									
LOW	46	0.036	0.225	0.191	0.030	1.025	-1.484	0.968	0
MED	63	.017	.020	.002	.012	1.143	-0.812	.625	0
HIGH	33	.022	.108	.093	.016	0.995	- .503	.481	0
Q/DA:									
LOW	47	0.021	0.147	0.118	0.018	1.001	-1.353	0.968	0
MED	46	.020	.151	.136	.015	1.061	-0.925	.696	0
HIGH	52	.032	.039	.015	.023	1.133	- .753	.516	0
AVE PRECIP:									
LOW	65	0.022	0.130	0.107	0.018	1.027	-0.885	0.689	0
MED	49	.024	.100	.080	.018	1.091	-1.032	.760	0
HIGH	31	.032	.083	.054	.024	1.115	-1.202	.721	0
AMI:									
LOW	40	0.034	0.099	0.073	0.029	1.332	-2.026	1.036	0
MED	52	.025	.116	.096	.019	0.986	-0.706	0.668	0
HIGH	43	.021	.105	.077	.015	.948	- .427	.450	0
SIF 3HR:									
LOW	46	0.010	0.117	0.105	0.006	0.873	-0.890	0.769	0
MED	47	.027	.091	.069	.021	1.065	- .694	.608	0
HIGH	42	.043	.116	.075	.036	1.311	-1.489	.752	0

Table 10d. Mean Relative Sensitivities for BMS Value on Day After Storm

CATEGORY	NUMBER STORM EVENTS	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:									
All Sites	145	0.053	0.098	0.042	0.044	0.938	-0.494	0.394	0
02191600	18	.083	.092	- .008	.072	.896	- .204	.224	0
02192400	26	.041	.045	.0001	.036	.963	- .142	.137	0
02410000	27	.035	.194	.157	.029	.866	- .695	.536	0
02435300	6	.100	.058	- .003	.074	1.459	-2.665	1.351	0
03431670	18	.049	.054	.0005	.040	0.784	-0.663	0.697	0
05558050	20	.058	.062	- .013	.051	1.001	- .118	.085	0
06909700	15	.052	.066	.025	.037	1.026	- .133	.109	0
07011500	15	.050	.170	.124	.038	0.880	- .886	.735	0
SEASONS:									
FALL	27	0.038	0.127	0.088	0.032	0.719	-0.485	0.446	0
WINTER	36	.015	.024	.008	.007	.972	- .190	.272	0
SPRING	57	.069	.104	.030	.057	1.016	- .435	.361	0
SUMMER	25	.085	.159	.068	.078	0.950	-1.078	.587	0
RO/RF:									
LOW	46	0.079	0.184	0.104	0.069	0.875	-0.606	0.438	0
MED	63	.034	.049	.007	.025	.945	- .352	.355	0
HIGH	33	.046	.072	.026	.037	1.010	- .307	.283	0
Q/DA:									
LOW	47	0.049	0.105	0.049	0.043	0.883	-0.551	0.457	0
MED	46	.057	.122	.064	.048	.861	- .314	.319	0
HIGH	52	.052	.070	.016	.040	1.056	- .602	.402	0
AVE PRECIP:									
LOW	65	0.048	0.091	0.041	0.039	0.923	-0.574	0.457	0
MED	49	.048	.071	.024	.038	.965	- .414	.360	0
HIGH	31	.072	.155	.073	.062	.928	- .454	.314	0
AMI:									
LOW	40	0.076	0.113	0.049	0.066	0.973	-0.963	0.561	0
MED	52	.054	.101	.040	.045	.927	- .370	.364	0
HIGH	43	.033	.090	.047	.023	.942	- .277	.303	0
SIF 3HR:									
LOW	46	0.030	0.076	0.044	0.022	0.875	-0.591	0.481	0
MED	47	.048	.064	.012	.039	1.000	- .422	.373	0
HIGH	42	.085	.170	.083	.075	0.962	- .539	.351	0

in the order of outputs mentioned above. The results of analyzing the coefficient of concordance in the form of the estimated true rankings are presented in Tables 11, 12, 13a, 13b, 13c, and 13d. These rankings show the least sensitive parameter as rank equal one. It should be noted that all 11 test sites with 189 storm events were used to analyze sensitivity relative to peak discharge while only 8 test sites with 145 storm events were used for the other two output types. The information contained in these tables makes it possible to define a hierarchy of parameter sensitivity and visualize how the parameters react to different type storm events. A discussion of this information is present in the context of the previously mentioned order of outputs.

Peak Discharge

The upper portions of Tables 8 and 11 illustrate parameter sensitivity for the test sites. The results show that PSP, KSAT, DRN, RGF, EVC, KSW and TC are negatively sensitive, RR and TP/TC are positively sensitive and BMSM acts with alternating sensitivity. While estimated rank determined from analysis of the concordance coefficient varies, KSAT, PSP and EVC are the three most consistent highly sensitive runoff producing parameters and KSW is the most sensitive routing parameter. RGF is consistently less sensitive than KSAT and PSP while RR is less sensitive than EVC except for two sites. TC is less sensitive than KSW except for two sites. The least sensitive parameters are consistently DRN and BMSM for the runoff producing portion and TP/TC for routing portion. However, this has not taken into account the alternating sensitivity of BMSM which is illustrated in

Table 11. Estimated True Rank of Relative Sensitivities from Analysis of Concordance Coefficient, W, for Peak Discharges

CATEGORY	NUMBER STORM EVENTS	W	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
TEST SITES:												
All Sites	189	0.563	9	10	1	5	3	8	6	7	4	2
02191600	18	.639	8	10	1	5	3	9	7	6	4	2
02192400	26	.706	8	10	1	5	4	9	6	7	3	2
02410000	11	.755	8	10	1	6	3	9	7	5	4	2
02410000	16	.558	9	10	2	5	3	8	7	6	4	1
02435300	6	.813	8	7	1	6	2	4	3	10	9	5
02488540	18	.647	8	10	1	7	3	6	4	9	5	2
03431670	21	.655	9	10	2	5	4	7	8	3	6	1
05495100	16	.632	7	10	2	5	3	9	8	6	4	1
05555400	7	.756	9	10	2	6	4	8	5	7	3	1
05558050	20	.586	9	10	1	5	3	7	6	4	8	2
06909700	15	.685	9	10	1	6	3	7	4	8	5	2
07011500	15	.689	6	9	2	4	3	7	8	10	5	1
SEASONS:												
FALL	35	0.399	9	10	1	5	3	8	7	6	4	2
WINTER	45	.444	8	10	1	3	4	7	6	9	5	2
SPRING	85	.394	8	10	1	4	3	9	6	7	5	2
SUMMER	47	.433	7	10	1	5	3	9	6	8	4	2
RO/RF:												
LOW	81	0.374	8	10	1	6	3	9	5	7	4	2
MED	79	.501	9	10	1	5	3	8	6	7	4	2
HIGH	47	.423	8	9	1	4	3	5	7	10	6	2
Q/DA:												
LOW	77	0.398	8	10	1	5	3	9	7	6	4	2
MED	73	.431	8	10	1	5	3	9	6	7	4	2
HIGH	62	.442	8	10	1	4	3	6	5	9	7	2
AVE PRECIP:												
LOW	90	0.485	9	10	1	5	3	8	6	7	4	2
MED	73	.441	8	10	1	4	3	7	6	9	5	2
HIGH	49	.304	5	8	1	4	3	9	7	10	6	2
AMI:												
LOW	56	0.525	9	10	1	6	3	8	5	7	4	2
MED	80	.441	8	10	1	4	3	9	7	6	5	2
HIGH	66	.324	7	10	1	4	3	5	8	9	6	2
SIF 3HR:												
LOW	75	0.435	9	10	1	5	3	8	7	6	4	2
MED	66	.376	7	10	1	4	3	8	6	9	5	2
HIGH	61	.392	7	10	1	4	3	8	6	9	5	2

NOTE - Least sensitive rank equal 1.

Table 12. Estimated True Rank of Relative Sensitivities from Analysis of Concordance Coefficient, W, for Storm Runoff Volumes

CATEGORY	NUMBER STORM EVENTS	W	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:										
All Sites	145	0.724	7	8	2	4	3	6	5	1
02191600	18	.771	6	8	2	4	3	7	5	1
02192400	26	.792	6	8	2	4	3	7	5	1
02410000	27	.684	7	8	2	4	3	6	5	1
02435300	6	.808	8	7	2	6	3	5	4	1
03431670	18	.807	6	8	2	4	3	7	5	1
05558050	20	.763	7	8	2	4	3	6	5	1
06909700	15	.805	7	8	2	5	3	6	4	1
07011500	15	.733	5	8	2	4	3	6	7	1
SEASONS:										
FALL	27	0.667	7	8	2	4	3	6	5	1
WINTER	36	.743	7	8	2	4	3	6	5	1
SPRING	57	.751	7	8	2	4	3	6	5	1
SUMMER	25	.729	6	8	2	4	3	7	5	1
RO/RF:										
LOW	46	0.766	6	8	2	5	3	7	4	1
MED	63	.734	7	8	2	4	3	6	5	1
HIGH	33	.708	7	8	2	4	3	5	6	1
Q/DA:										
LOW	47	.735	6	8	2	4	3	7	5	1
MED	46	.767	6	8	2	4	3	7	5	1
HIGH	52	.695	7	8	2	4	3	6	5	1
AVE PRECIP:										
LOW	65	0.709	7	8	2	4	3	6	5	1
MED	49	.740	7	8	2	4	3	6	5	1
HIGH	31	.735	6	8	2	4	3	7	5	1
AMI:										
LOW	40	0.772	7	8	2	5	3	6	4	1
MED	52	.784	6	8	2	4	3	7	5	1
HIGH	43	.665	7	8	2	4	3	5	6	1
SIF 3HR:										
LOW	46	0.695	7	8	2	4	3	6	5	1
MED	47	.730	7	8	2	4	3	6	5	1
HIGH	42	.760	7	8	2	4	3	6	5	1

Table 13a. Estimated True Ranking of Relative Sensitivities from Analysis of Concordance Coefficient, W, for BMS Value on Day Previous to Storm

CATEGORY	NUMBER STORM EVENTS	W	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:										
All Sites	145	0.760	2	3	5	4	8	6	7	1
02191600	18	.802	2	3	4	5	8	6	7	1
02192400	26	.914	2	3	4	5	8	7	6	1
02410000	27	.770	2	4	5	3	8	7	6	1
02435300	6	.946	2	3	4	5	6	8	7	1
03431670	18	.782	2	4	3	5	8	6	7	1
05558050	20	.814	2	4	3	5	8	6	7	1
06909700	15	.743	2	4	5	3	8	7	6	1
07011500	15	.839	2	4	5	3	7	6	8	1
SEASONS:										
FALL	27	0.716	2	5	3	4	7	6	8	1
WINTER	36	.857	2	3	4	5	8	6	7	1
SPRING	57	.752	2	4	5	3	8	7	6	1
SUMMER	25	.767	2	3	4	5	7	8	6	1
RO/RF:										
LOW	46	0.759	2	3	4	5	7	8	6	1
MED	63	.759	2	4	5	3	8	6	7	1
HIGH	33	.804	2	3	5	4	8	6	7	1
Q/DA:										
LOW	47	0.773	2	3	4	5	8	7	6	1
MED	46	.760	2	3	5	4	8	6	7	1
HIGH	52	.760	2	4	5	3	8	6	7	1
AVE PRECIP:										
LOW	65	0.770	2	3	5	4	8	6	7	1
MED	49	.771	2	3	5	4	8	6	7	1
HIGH	31	.736	2	4	5	3	8	7	6	1
AMI:										
LOW	40	0.780	2	3	5	4	8	7	6	1
MED	52	.777	2	3	5	4	8	6	7	1
HIGH	43	.726	2	5	4	3	8	6	7	1
SIF 3HR:										
LOW	46	0.765	2	3	4	5	8	6	7	1
MED	47	.787	2	3	5	4	8	6	7	1
HIGH	42	.731	2	4	5	3	8	7	6	1

Table 13b. Estimated True Ranking of Relative Sensitivities from Analysis of Concordance Coefficient, W, for Storm Average Value of SMS

CATEGORY	NUMBER STORM EVENTS	W	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:										
All Sites	145	0.339	7	4	8	3	2	6	5	1
02191600	18	.547	7	3	8	4	2	5	6	1
02192400	26	.704	8	6	2	5	3	7	4	1
02410000	27	.563	7	5	8	3	2	6	4	1
02435300	6	.079	-							*
03431670	18	.618	7	4	8	3	2	5	6	1
05558050	20	.387	4	5	8	3	2	6	7	1
06909700	15	.510	6	7	8	2	3	4	5	1
07011500	15	.434	7	4	8	3	2	5	6	1
SEASONS:										
FALL	27	0.460	7	6	8	3	2	5	4	1
WINTER	36	.391	8	6	4	2	3	5	7	1
SPRING	57	.311	7	4	8	3	2	6	5	1
SUMMER	25	.354	6	4	8	3	2	7	5	1
RO/RF:										
LOW	46	0.419	7	5	8	4	2	6	3	1
MED	63	.338	7	4	8	3	2	5	6	1
HIGH	33	.293	6	4	8	2	3	5	7	1
Q/DA:										
LOW	47	0.486	8	5	7	4	2	6	3	1
MED	46	.418	8	4	7	3	2	6	5	1
HIGH	52	.290	4	6	8	3	2	5	7	1
AVE PRECIP:										
LOW	65	0.373	7	6	8	3	2	5	4	1
MED	49	.311	6	4	8	3	2	5	7	1
HIGH	31	.356	6	4	8	3	2	7	5	1
AMI:										
LOW	40	0.377	7	5	8	3	2	6	4	1
MED	52	.331	5	4	8	3	2	6	7	1
HIGH	43	.401	7	6	8	2	3	4	5	1
SIF 3HR:										
LOW	46	0.335	7	6	8	3	2	4	5	1
MED	47	.309	5	6	8	3	2	4	7	1
HIGH	42	.436	7	3	8	4	2	6	5	1

* - W not significant.

Table 13c. Estimated True Ranking of Relative Sensitivities from Analysis of Concordance Coefficient, W, for Storm Average Value of BMS

CATEGORY	NUMBER STORM EVENTS	W	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:										
All Sites	145	0.756	3	5	4	2	8	7	6	1
02191600	18	.813	3	5	4	2	8	6	7	1
02192400	26	.935	2	4	5	3	8	7	6	1
02410000	27	.777	3	5	4	2	8	6	7	1
02435300	6	.659	3	5	4	2	8	7	6	1
03431670	18	.845	3	5	4	2	8	6	7	1
05558050	20	.767	3	5	4	2	8	7	6	1
06909700	15	.734	3	6	4	2	8	7	5	1
07011500	15	.766	3	4	5	2	6	7	8	1
SEASONS:										
FALL	27	0.740	3	5	4	2	8	6	7	1
WINTER	36	.900	2	4	5	3	8	6	7	1
SPRING	57	.767	3	5	4	2	8	7	6	1
SUMMER	25	.666	3	5	4	2	7	8	6	1
RO/RF:										
LOW	46	0.760	3	5	4	2	8	7	6	1
MED	63	.777	3	5	4	2	8	6	7	1
HIGH	33	.747	3	4	5	2	8	6	7	1
Q/DA:										
LOW	47	0.805	2	5	4	3	8	7	6	1
MED	46	.794	3	5	4	2	8	6	7	1
HIGH	52	.717	3	5	4	2	8	7	6	1
AVE PRECIP:										
LOW	65	0.791	3	5	4	2	8	7	6	1
MED	49	.766	3	5	4	2	8	7	6	1
HIGH	31	.676	3	5	4	2	8	7	6	1
AMI:										
LOW	40	0.728	3	5	4	2	8	7	6	1
MED	52	.799	3	5	4	2	8	6	7	1
HIGH	43	.729	3	5	4	2	8	7	6	1
SIF 3HR:										
LOW	46	0.794	3	5	4	2	8	6	7	1
MED	47	.729	3	5	4	2	8	7	6	1
HIGH	42	.748	3	5	4	2	8	7	6	1

Table 13d. Estimated True Ranking of Relative Sensitivities from Analysis of Concordance Coefficient, W, for BMS Value on Day After Storm

CATEGORY	NUMBER STORM EVENTS	W	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	ROUTING
TEST SITES:										
All Sites	145	0.605	3	5	4	2	8	6	7	1
02191600	18	.617	4	5	2	3	8	6	7	1
02192400	26	.679	3	5	2	4	8	6	7	1
02410000	27	.755	3	5	4	2	8	6	7	1
02435300	6	.775	5	4	2	3	8	7	6	1
03431670	18	.855	4	5	2	3	8	6	7	1
05558050	20	.581	4	5	3	2	8	7	6	1
06909700	15	.572	3	7	5	2	8	6	4	1
07011500	15	.720	3	5	4	2	7	6	8	1
SEASONS:										
FALL	27	0.574	3	5	4	2	8	6	7	1
WINTER	36	.691	2	5	4	3	8	6	7	1
SPRING	57	.667	4	5	3	2	8	7	6	1
SUMMER	25	.563	4	5	3	2	8	7	6	1
RO/RF:										
LOW	46	0.609	4	5	3	2	8	7	6	1
MED	63	.658	3	5	4	2	8	6	7	1
HIGH	33	.584	3	5	4	2	8	6	7	1
Q/DA:										
LOW	47	0.667	4	5	3	2	8	6	7	1
MED	46	.611	3	5	4	2	8	6	7	1
HIGH	52	.573	3	5	4	2	8	7	6	1
AVE PRECIP:										
LOW	65	0.688	3	5	4	2	8	6	7	1
MED	49	.569	4	5	3	2	8	6	7	1
HIGH	31	.550	3	5	4	2	8	7	6	1
AMI:										
LOW	40	0.579	4	5	2	3	8	7	6	1
MED	52	.655	4	5	3	2	8	6	7	1
HIGH	43	.595	3	5	4	2	8	7	6	1
SIF 3HR:										
LOW	46	0.675	3	5	4	2	8	6	7	1
MED	47	.613	4	5	3	2	8	6	7	1
HIGH	42	.603	3	5	4	2	8	7	6	1

Appendix C, Figures C.2, C.5 and C.7. Thus, BMSM can not be dealt with in the same manner as the other parameters. Its sensitivity is more easily viewed as it relates to its use in the Model and is dealt with in the next section. Examination of the mean relative sensitivities of Table 8 show that the routing parameters, KSW and TC, exhibit a much smaller range of sensitivity than the runoff producing parameters, PSP, KSAT, RGF, EVC and RR. This is attributed to the direct affect of the input data set composition on the runoff producing portion of the Model. Stations 02435300, 05558050 and 07011500 in Table 8 have the lowest absolute relative sensitivity values for PSP, KSAT and RGF, and with one exception, EVC. Referring to Table 7, it is shown that these sites have data sets composed of a higher percentage of high Q/DA storm events compared to the other test sites. This influence of data set composition is also apparent in the lower portion of Tables 8 and 11. The categories defining storm event types, RØ/RF, Q/DA, AVE PRECIP, AMI and SIF-3HR, consistently show that the absolute sensitivity of these infiltration and moisture accounting parameters, PSP, KSAT, RGF, and EVC, and RR decrease as these processes become less significant in producing the peak discharge. In contrast, the routing parameters, KSW and TC, exhibit consistent sensitivity throughout the range of event types. This information makes it possible to judge whether or not an input data set has a sufficient variety of storm event types to insure that the sensitive runoff producing parameters are actually brought into the Model operation. For example, the insensitivity exhibited by these parameters at station 02435300 leads to the conclusion that the resulting values of PSP, KSAT, RGF, EVC and RR are not acceptable. However, the routing parameters, KSW and TC, are acceptable as their sensitivities fall much closer to the values shown for the various storm event types.

Runoff Volumes

The upper portions of Tables 9 and 12 illustrate the parameter sensitivity for the test sites. The results show that PSP, KSAT, DRN, RGF and EVC are negatively sensitive, RR is positively sensitive and BMSM acts with alternating sensitivity. The three routing parameters, referred to here collectively under the heading ROUTING, have no influence on computation of runoff volumes and are not mentioned further. Except for the aforementioned station 02435300, KSAT ranks as the most sensitive parameter in producing volumes with PSP and EVC exhibiting the most consistently high sensitivity for the remaining parameters. RGF and RR exhibit almost equal though opposite sensitivities at the various sites. As with peak discharges, RGF is consistently less sensitive than KSAT and PSP, while RR is less sensitive than EVC with the exception of one site. DRN is the consistently least sensitive parameters. As mentioned under peak discharges, BMSM is dealt with in the next section due to its nonlinearity.

The discussion with respect to input data composition in the preceding section also applies here. The three stations, 02435300, 05558050 and 07011500, have the lowest sensitivities for all 7 runoff producing parameters, PSP, KSAT, DRN, RGF, BMSM, EVC and RR. The lower portion of Tables 9 and 12 also show this influence of data set composition. The categories defining storm event types, RØ/RF, Q/DA, AVE PRECIP, AMI and SIF-3HR, consistently show that the absolute sensitivity of PSP, KSAT, RGF, EVC and RR (with the exception of AMI) decreases as the processes modelled become less significant in producing runoff volume compared to the rainfall input data. Again the conclusion is reached that if the input data set did not contain a sufficient variety of storm events these parameters, PSP, KSAT, RGF, EVC and RR, could not have been sufficiently activated in the Model to be calibrated properly.

Moisture Storage Values

The status of moisture storage represent the antecedent conditions applicable to the production of peak discharge and storm runoff volume. The sensitivity of the seven runoff producing parameters to moisture storage is viewed by studying the effects of changing parameters to (1) base moisture storage value on the day preceding the storm event, BMS MINUS, (2) the storm average value for surface moisture storage, SMS, (3) the storm average value for base moisture storage, BMS, and (4) the value for base moisture storage on the day following the storm, BMS PLUS.

Appendix C, Figures C.10 through C.17, show a typical response of the moisture storages with varying parameters. Of particular interest, Appendix C, Figures C.11, C.13 and C.17, show that BMSM exhibits linear positive sensitivity for base mositure storage.

The upper portions of Tables 10a, 10b, 10c, 10d, 13a, 13c and 13d illustrate the parameter sensitivity for the test sites. As expected, ROUTING has no influence on moisture storage and is not mentioned in this section. The results with respect to base moisture storage, BMS MINUS, BMS and BMS PLUS, show that BMSM and RR are positively sensitive, EVC is negatively sensitive and PSP, KSAT, DRN and RGF are insensitive (Tables 10a, 10c, 10d and 13a, 13c 13d). BMSM is the most sensitive parameter effecting base moisture storage although EVC and RR also show high sensitivity.

The results with respect to surface moisture storage, SMS, show that KSAT, DRN and RR are negatively sensitive and PSP, RGF and EVC are positively sensitive (Tables 10b and 13b). DRN and PSP exhibit the most consistent high sensitivity. BMSM is not considered as it exhibits alternating sensitivity (Appendix C, Figure C.15). KSAT, RGF, EVC and RR exhibit roughly equivalent sensitivity.

The influence of data set composition may again be viewed by a study of the three stations, 02435300, 05558050, and 07011500, and the lower portions of Tables 10a, 10b, 10c, 10d, 13a, 13b, 13c and 13d. The parameters insensitive with respect to base moisture storage, PSP, KSAT, DRN and RGF, show no definitive trend with changes within storm event types. BMSM, EVC and RR exhibit some tendencies toward such a trend. In a similar fashion, no consistent trends are exhibited by these parameters with respect to surface moisture storage. However, the differences between the three sites and the remaining test sites for the moisture storage is not nearly as great as shown for peak discharges and volumes. Thus, it is not possible to determine a clear measure of the influence of data set composition upon these seven parameters as they relate to moisture storage.

Analysis of Results

The determination of a parameter's sensitivity provides an insight into the significance of that parameter. The preceding section results can be generalized into a hierarchy of parameter sensitivity presented in Table 14. This hierarchy shows that for the principal outputs of the Model, peak discharge and runoff volume, the infiltration component, as represented by KSAT, PSP and RGF, is the most significant part of the runoff producing portion of the model. The production of the peak discharge by the routing component is more sensitive to KSW than TC. The accumulation of moisture in base moisture storage depends primarily on BMSM, EVC and RR. The accumulation of moisture in surface moisture storage depends primarily on DRN and PSP. An analysis of these results allows evaluation of the significance of these parameters.

The significance of the infiltration component to a rainfall-runoff model has been apparent to many investigators.[4/] Thus, its significance to this Model comes as no surprise. The component is defined with the parameters KSAT, PSP, RGF, and BMSM and is represented by equation (IV.1). This equation shows that the infiltration rate is always affected by KSAT, PSP varies in its affect due to the value of SMS and BMS, RGF enters the equation based on BMS, and BMSM serves as an upper limit for BMS. The effects of KSAT and PSP appear more direct than the more subtle effects of RGF and BMSM. The sensitivity of BMSM is apparent if it is examined in light of this equation.

[4/] See footnote no. 2 in Chapter III.

Table 14. Hierarchy of Model Parameter Sensitivity

MODEL OUTPUT	ORDER OF PARAMETER SENSITIVITY									
	RUNOFF PRODUCING PARAMETERS							ROUTING PARAMETERS		
	1	2	3	4	5	6	7	1	2	3
PEAK DISCHARGE	KSAT	PSP	EVC	RGF	RR	BMSM[c]	b	KSW	TC	b
RUNOFF VOLUME	KSAT	PSP	EVC	RGF	RR	BMSM[c]	b	a	a	a
MOISTURE STORAGE										
(1) BMS MINUS	BMSM	EVC	RR	b	b	b	b	a	a	a
(2) SMS	DRN	PSP	KSAT	RGF	EVC	RR	b	a	a	a
(3) BMS	BMSM	EVC	RR	b	b	b	b	a	a	a
(4) BMS PLUS	BMSM	EVC	RR	b	b	b	b	a	a	a

a - indicates no influence.
b - indicates insensitive parameter.
c - alternating sensitivity masks actual place in hierarchy.

Increasing BMSM causes the infiltration rate to increase if BMS would remain the same. However, increasing BMSM does not allow BMS to stay the same as the pattern of BMS values changes. Thus, the actual direction of sensitivity for BMSM could vary within a storm event. The results of the analysis of sensitivity confirm this significance of the component.

The sensitivity analysis also confirms that the infiltration component and moisture accounting component are acting hydrologically sound. This is seen from the examination of the lower portions of Tables 8, 9, 11 and 12 which show that as the watershed produces more efficiently the losses represented by infiltration and direct moisture losses of evapotranspiration become less significant. Thus, the decrease in relative sensitivity is expected for KSAT, PSP, RGF, and EVC as storm size increases. The effect of RR is not as clear but it does show a decrease considering the larger events compared to both medium and smaller events combined. This decrease in sensitivity coupled with the stable sensitivity exhibited by the routing parameters, KSW and TC, cause changes in the overall ranking of the parameter sensitivity for computing peak discharges for larger storm events. Thus, the rank of parameters which are most significant at smaller storm events, KSAT, PSP, EVC and RGF, tend to decrease at larger events, while the rank for KSW and TC tend to increase. Although effect of BMSM depends on the pattern of BMS values, its influence on the infiltration rate make it more significant for smaller than larger events.

The accumulation of moisture in base moisture storage is most sensitive to the moisture accounting component. The majority of time finds base moisture storage affected by daily, as opposed to unit, rainfall and the parameters BMSM, EVC and RR. Thus, it follows that these parameters would be the most significant for accumulating storage in base moisture storage.

The accumulation of moisture in surface moisture storage is accomplished by increases during infiltration and drainage when there is no rainfall available. The increases are functions of PSP, KSAT and RGF and the decreases are functions of DRN and EVC. The effect of RR is more subtle than the others and is based on RR's positive influence on BMS which decreases the infiltration rate.

This section has defined parameter significance in terms of parameter sensitivity to Model output. Nine of the model parameters, KSAT, PSP, RGF, EVC, RR, BMSM, DRN, KSW and TC, were shown to have some degree of significance with respect to these chosen Model outputs. Table 14 indicates the relative order of this significance. The final section of this chapter expresses the conclusion reached with respect to how this information applied to this study.

Conclusions

The Model has been developed to produce storm event peak discharges and runoff volumes. In order to apply the Model at ungaged sites this study is attempting to relate the parameters to physical characteristics of the drainage basins. The decision to relate a particular parameter to the basin characteristics depends on its significance within the Model operation. This chapter has defined this significance in terms of the parameter's sensitivity as measured by its effect on the outputs when the parameter value has been varied. The parameter's sensitivity is also important for another reason. The sensitivity of the parameter to the observed output determines the ease with which it can be calibrated according to the process explained in Chapter II. This implies that the more sensitive a parameter the easier it is to determine a meaningful value.

The high linear sensitivity exhibited by KSAT, PSP, EVC, RGF and RR with respect to both peak discharges and runoff volumes make it apparent that these parameters can be determined through the aforementioned calibration process. This same statement applies to the high linear sensitivity exhibited by KSW and TC with respect to peak discharges. However, the data set composition was shown to have a pronounced influence on the sensitivities of KSAT, PSP, EVC, RGF and RR. This is interpreted to mean that the data set composition must be examined to insure that it contains a sufficient range of storm events so that all of the parameters will enter into the model operation. Referring again to test site station 02435300, this would mean that the values determined at this site using the calibration process for KSAT, PSP, EVC, RGF and RR would not be acceptable due to the very low sensitivity exhibited by each. This low sensitivity means that regardless of the values given KSAT, PSP, EVC, RGF and RR, the Model output will vary little. Thus, the infiltration process has little or no effect on the storm events used for this site. Also, it is noted in Table 7 that all of the events for this site are classified as HIGH (defined in Table 6) for both RO/RF and Q/DA. This analysis of the data set composition and knowledge of the sensitivities indicate that storm events classed as LOW for both RO/RF and Q/DA should be present in the data set for this site to properly calibrate KSAT, PSP, EVC, RGF and RR. In contrast, the stability exhibited by the sensitivities for KSW and TC is interpreted to mean data set composition in terms of a complete range of storm events is not as critical to their determination. It is felt that due to the higher significance of KSW and TC for storm events classed as HIGH for both RO/RF and Q/DA, the data set should contain these larger events.

Two of the three remaining parameters, DRN and TP/TC, are virtually insensitive in terms of their effects on peak discharge and runoff volume. However, DRN was shown to be sensitive to the value of surface moisture storage, SMS. Unfortunately, the observed data does not contain a measure, either direct or indirect, of the storage values. Consequently, DRN can not be determined by applying the calibration process to these moisture storage values. The determination of these two parameters by using the calibration process with peak discharges or runoff volumes would not necessarily yield acceptable values.

The final parameter, BMSM, exhibits sensitivity alternating between positive and negative with respect to peak discharge and storm runoff volume, and linear positive sensitivity with respect to the value of base moisture storage. However, as with surface moisture storage, the observed data did not contain a measure of this storage. Thus, BMSM could only be determined using the calibration process with the peak discharges or runoff volumes. It appears that the data set for determining BMSM must cover the range of events to insure that BMSM enters the Model operation.

As mentioned previously, the relative sensitivities were computed by not restricting the parameter values to a reasonable upper bound. Only four of the parameters should not exceed an upper bound value. These are DRN, EVC, RR and TP/TC, and the reasons that they must stay within bounds are as follows:

(1) DRN represents drainage from the saturated section to the unsaturated section. It should be less than or equal to 1.0 as it is inputted as a proportion of KSAT. KSAT is a measure of hydraulic conductivity in the saturated section which will not be less than that in the unsaturated section (Todd, 1967).

(2) EVC should be less than 1.0 and, in fact, within the limits of annual pan coefficient for a U.S. Weather Bureau Class A pan, 0.6 to 0.9. These apply as it is intended to convert Class A pan data to potential evapotranspiration as represented by lake evaporation (Dawdy et al., 1972).

(3) RR can not exceed 1.0 unless the daily rainfall data is not representative for the basin because if it exceeds 1.0; then more daily rainfall is added to moisture storage than is actually inputted.

(4) TP/TC can not exceed 1.0 because the time to peak for a discharge hydrograph can not be greater than the basin time of concentration.

Figures C.2, C.5 and C.8 in Appendix C show that the variation of RR and EVC above the upper bound can have a pronounced effect on not only the resulting output but also the measure of sensitivity. While DRN and TP/TC were so insensitive that variation of their values above the proper upper bound did not affect an appraisal of their sensitivity to the computation of peak discharge and storm runoff volumes, it was decided that the values for these four parameters must be limited to values equal to or below the bounds mentioned. This information is applied in a following chapter.

Thus, an analysis of parameter sensitivity has generated the following guidelines with respect to this study. The parameters KSAT, PSP, RGF and BMSM may be assumed to be properly determined by the calibration process if the data set is composed of a sufficient range of storm event types defined along the bounds given in Table 6. In similar fashion, KSW and TC may be assumed to be properly determined by the calibration process if the data set contains storm events whose RO/RF or Q/DA value fall into the HIGH category of Table 6, i.e., the larger storm events. The remaining parameters, EVC, RR, DRN and TP/TC, must be viewed within their proper bounds. A following chapter will implement these guidelines as a basis to judge whether or not a parameter has been assigned a value during the calibration phase which is acceptable to this study.

CHAPTER V

THE DETERMINATION OF PHYSICAL BASIN CHARACTERISTICS

Introduction

The data requirements for this study can be grouped into two classes. The first of these is the set of parameter values which will be used as dependent variables. These were available at the 344 drainage basin sites used in the U.S.G.S.-FHA studies referred to in Table 1. The second class is the set of physical basin characteristics which will serve as independent variables. A small set of basin characteristics was available for these 344 sites as a result of the U.S.G.S.-FHA program goal to develop regionalized relationships to predict flood frequency characteristics. For most sites, this set included drainage area, main channel length, main channel slope, surface storage area, mean basin elevation, forest area, mean annual precipitation and a precipitation intensity measure. This set was not adequate since more characteristics, especially for soils, were desired for this study; an expanded set was developed.

The additional basin characteristics were required to develop more intuitive relations with the model parameters. The selected basin characteristics are grouped in three categories. The first category is termed "descriptive" basin characteristics because it is concerned with measures of size, shape and topography of the drainage basin.

The second category is concerned with the soils of the basin. The third category is concerned with measures of the climate for a drainage basin.

The data sources for these categories were U.S.G.S. topographic maps for the descriptive characteristics, USDA Soil Conservation Service soils maps and surveys for the soils information, and publications of the U.S. Weather Bureau (now National Weather Service) for information pertaining to climate. The limited number of soils maps and surveys available made it necessary to delete sites from the total 344 available so that a complete set of basin characteristics could be collected. Thus, this study was able to determine a complete set for 228 sites. These 228 sites serve as the final data set for this study. Appendix D, Table D.1, lists these sites, and they are also located on Figure 9.

The purpose of this chapter is to present this complete set of physical basin characteristics. The definitions of each characteristic and the method by which each was determined is presented in the following sections for the categories mentioned above. A final summary section mentions a general evaluation of the selected characteristics.

Descriptive Basin Characteristics

This category represent characteristics which describe the drainage basin with respect to size, shape and topography. The data sources used were the appropriate U.S.G.S. topographic maps in the 7 1/2 or 15 minute series. A total of seventeen basin characteristics were determined for this category. These include drainage area, basin perimeter, a compactness coefficient, mean basin elevation,

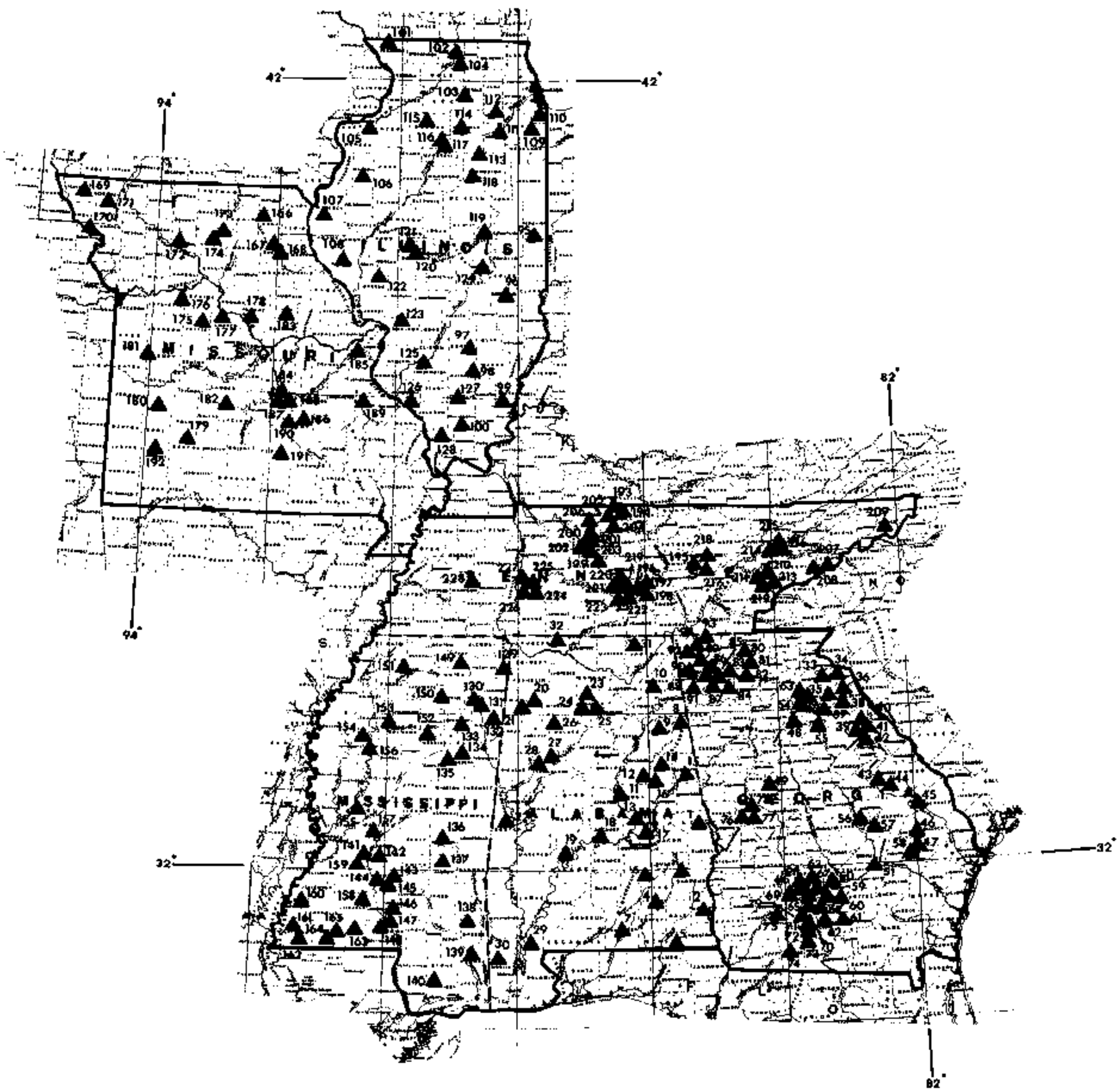

Figure 9. Location of the 228 Sites used for Study

maximum relief, main channel length, main channel slope, a relief ratio, average basin width, a basin shape factor, mean overland flow length, mean overland flow slope, total length of all channels, drainage density, surface storage area, forested area, and impervious area. These are discussed in this section with respect to their definition, and the manner in which they were determined. Appendix D, Table D.2, lists the actual values determined according to the identifiers included with the discussions.

(1) Drainage area, A, was determined for the previous studies. It represents the total contributing area, in square miles, at the gage.

(2) Perimeter, P, was determined by measuring the continuous ridge line for the drainage basin. Its value is in miles.

(3) Compactness coefficient, CC, is the ratio of the watershed perimeter as measured to that of a circle of equal area. This may be be expressed as

$$CC = P/2\sqrt{\pi A} \tag{V.1}$$

It is dimensionless.

(4) Mean basin elevation, E, was available for some sites from the previous studies. However, as it was not available at all 228 sites, a uniform procedure was adopted to select the mean. A grid of 10 to 20 points was established depending on drainage basin size and the mean basin elevation was determined as the average of those grid points. Its value is in feet above mean sea level.

(5) Maximum relief, RMAX, is the difference in elevation between the high point of the drainage basin and the zero datum at the gaging station. Its value is in feet.

(6) Main channel length, L, was determined for the previous studies. It is the stream length, in miles, measured along the main channel from the gaging station to the basin divide.

(7) Main channel slope, S, was determined for the previous studies. It is the average slope between points 10 percent and 85 percent of the distance from the gaging station to the basin divide. It was computed as the difference in elevation between these two points divided by the length between them. Its value is in feet per mile.

(8) Relief ratio, RRAT, is defined as the ratio of the maximum relief value, RMAX, to main channel length, L. Its value is in feet per mile.

(9) Average basin width, W, is computed by dividing the drainage area, A, by the main channel length, L. Its value is in miles.

(10) Basin shape factor, SHAPE, is defined as the ratio of the average basin width, W, to the main channel length, L. It is dimensionless.

(11) Mean overland flow length, OVL, is defined as the average distance overland flow must travel before reaching a stream channel. It was determined by computing the average for 10 to 20 grid points depending on drainage basin size. Each measure of overland flow length was determined as the length of a line drawn from the grid points perpendicular to the contours on the topographic map and extending to

the ridge and to the nearest definable channel. Its value is in miles.

(12) Mean overland flow slope, OVS, is defined as the average slope of the overland flow surfaces perpendicular to the receiving channel. It was determined by computing the slope values for the line segments required to define overland flow length, OVL, and averaging the results. Its value is in feet per mile.

(13) Total length of all channels, LCHAN, is defined as the sum of the lengths of all definable channels on the topographic map. Its value is in miles.

(14) Drainage density, DD, is defined as the ratio of the total length of all channels, LCHAN, to the total drainage area, A. Its value is in miles per square mile.

(15) Surface storage area, ST, was determined for the previous studies. It is defined as the area of lakes, ponds and swamps represented as a percent of the total contributing drainage area.

(16) Forested area, F, was determined for the previous studies. It is the amount of forested area in a drainage basin represented as a percent of the total contributing drainage area.

(17) Impervious area, I, was determined for the previous studies. It is the total amount of impervious area in a drainage basin represented as a percent of the total contributing area.

The basin characteristics presented in this section describe various aspects of the drainage basin. Their application in this study is presented in a later chapter.

Soils Characteristics

This category represents characteristics of the soil coverage of the drainage basin. The data were required for the development of relationships with the parameters of the infiltration and moisture accounting components. The source of information on soil coverage and soil properties was a series of soil surveys and maps prepared by the Soil Conservation Service, U.S. Department of Agriculture. These publications are available on a county or regional basis within a particular state, although complete coverage of the six state study region is not available. As mentioned previously, this fact caused the reduction in sites available for this study from 344 to 228. The SCS has prepared these publications since the early 1900's. Those publications prior to about 1951 do not contain as much information as the later ones. However, comparisons between several sets of "old" and "new" soil surveys showed that the basic information did not vary. Averaged values obtained from "new" soil surveys were used where needed in obtaining usable values from "old" soil surveys.

The basic information supplied by these soil surveys are the identity of the various soil types covering the drainage basin. A grid sampling technique was used to determine the percent composition of soils, by name and type, covering the basin. Various properties of the soils were also available. These included depth to bedrock and for definable layers of soil, available water capacity,[1/] and

[1/]Available water capacity is defined as the difference between the amount of soil water at field capacity and the amount at wilting point.

permeability.[2/] The soils characteristics are a result of interpreting this information. These soils characteristics are divided into three general groups which are soil types and composition, soil indices determined from applying SCS definitions and soil indices determined from theoretical considerations. They are discussed in this section with respect to their definitions and the manner in which they were determined.

The various soils were classified into 12 separate soil textural classes by the SCS according to published guidelines in the Soil Survey Manual (Soil Survey Staff, 1951) in order to define the first category of soils characteristics. These are sands, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay and clay. Table 15 presents the percent composition in terms of sand, silt and clay for them. The soils identified by the grid sampling technique were catalogued as one of these specific 12 types, if possible, by the soil surveys at each site. Soils not so catalogued were lumped under a general class. Information with respect to coarse material was also available. Appendix D, Table D.3, presents the resulting estimate of the percent of the drainage area covered by the soils grouped in one of the 13 classes. Appendix D, Table D.4, presents an estimate of the sand, silt, clay and coarse material portion of this soils coverage in terms of a percent of the drainage area.

[2/] Permeability refers to the ease with which water passes through the soil and is defined in terms of Darcy's law as the coefficient or constant of proportionality between velocity of water movement through a soil and the slope of the hydraulic gradient moving the water.

Table 15. Composition of Soil Types*

NO	TYPES	LIMITS OF COMPOSITION, % SAND	SILT	CLAY	OTHER REQUIREMENTS
(1)	Sands	≥ 85			Silt + 1.5 x Clay ≤ 15
(2)	Loamy Sands	UPPER: 85-90 LOWER: 70-85			Silt + 1.5 x Clay ≥ 15 Silt + 2.0 x Clay ≤ 30
(3)	Sandy Loams	EITHER: > 52 OR: 43-52	 < 50	≤ 20 < 7	
(4)	Loam	< 52	28-50	7-27	
(5)	Silt Loam	EITHER: OR:	> 50 50-80	12-27 < 12	
(6)	Silt		≥ 80	< 12	
(7)	Sandy Clay Loam	≥ 45	< 28	20-35	
(8)	Clay Loam	20-45		27-40	
(9)	Silty Clay Loam	< 20		27-40	
(10)	Sandy Clay	≥ 45		≥ 35	
(11)	Silty Clay		≥ 40	≥ 40	
(12)	Clay	< 45	< 40	≥ 40	

*According to Soil Survey Manual

These values were computed by estimating appropriate values from Table 15. The primary use of this group defining soil types and composition as given by the values listed in Appendix D, Tables D.3 and D.4, was to compute drainage basin average values for the various soils indices for the remaining two groups. The values for these indices, those determined from applying SCS definitions and those determined from theoretical considerations, are given in Appendix D, Table D.5, and are explained below.

The information furnished by the SCS through the soil surveys and the classification of soils by their hydrologic behavior[3/] enabled the computation of five soil indices. These are referred to as (1) depth to bedrock, (2) average available water capacity, (3) average permeability of the surface layer, (4) average permeability, and (5) an infiltration value resulting from considering the SCS hydrologic soil groupings. These are defined below including the identifier used in Appendix D, Table D.5, and subsequent chapters of this report.

(1) Depth to bedrock, DBR, is the basin average value computed by considering the individual values given soils in the soil survey and weighing them by the percent of the total area which that soil represents. Its value is in inches. Its accuracy is not considered to be good, but it is an index to a low value for actual depth to bedrock.

(2) Average available water capacity, AVE AWC, is determined

[3/] Table 7.1 in Section 4, Hydrology, Part 1--Watershed Planning, of the National Engineering Handbook, U.S. Soil Conservation Service, Washington, D.C., 1966.

by considering the midrange value of available water capacity given for the various layers of a soil. The contribution for each soil is computed as the sum of the products of each layer for its midrange value times the thickness of that layer. The average value for the basin is then determined by weighing each soil by its percent of the total area. Its value is in inches and should be an index of the basins limit for storing moisture.

(3) Average permeability of the "A" horizon or surface layer, AHOR PERM, is determined by computing the midrange value given for permeability of the initial or surface layer by the soil survey for each soil. The basin average is then determined as mentioned. Its value is in inches per hour. It should be indicative of the controlling infiltration rates for the basin.

(4) Average permeability, AVE PERM, is determined for a soil by computing the sum of products for each layer of the midrange value of permeability times the ratio of the layer depth to the total soil depth. The basin average is then determined as mentioned. Its value is in inches per hour. As with AHOR PERM, it is considered indicative of the controlling infiltration rates.

(5) An infiltration value based on the SCS hydrologic soil groupings, HSG INFIL, was computed by determining the proper hydrologic soil group for a particular soil and then appyling the minimum infiltration rates indicated for these groupings by Musgrave, (1955). The basin average was then computed as mentioned. Its value is in inches per hour. As with the previous two indices, its value is considered

indicative of the controlling infiltration rates for the basin.

Considerations of soil physics theory also were used to determine indices.[4/] These relied on interpolation of moisture tension data[5/] to produce actual numerical values. The indices are (1) a measure of saturated hydraulic conductivity, (2) a measure of unsaturated hydraulic conductivity, (3) a measure of effective capillary potential at field capacity, (4) a measure of the ratio of effective capillary potential at wilting point to that at field capacity, where wilting point is defined as the moisture content where moisture is retained with a tension of 15 bars (15000 cms), and (5) a similar measure of the ratio in (4) except wilting point is defined at a tension of 3 bars (3000 cms). These are defined below including the identifier with which their values are given in Appendix D, Table D.5.

(1) A measure of saturated hydraulic conductivity, MEAS KSAT, is determined by considering the values of saturated hydraulic conductivity recorded for experimental watersheds as mentioned. Considering the experimental watersheds available in the ARS publication (Holtan et al., 1968) for this study area, mean values were determined for the 12 soil types. This was done by using the saturated hydraulic conductivity for the upper layers of the appropriate soils according to their soil types. The mean value was then computed by considering all soils of a particular type. This mean value was then always used for that

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[4/] Bayer, L.D., 1963.

[5/] Holtan, H. N. et al., 1968.

soil type. A basin average value was computed as mentioned previously. Its value was in inches per hour. It should be indicative of either the parameter, KSAT, or the infiltration process.

(2) A measure of unsaturated hydraulic conductivity, MEAS KUN, is determined by considering conductivity data developed by Green and Corey (1971) for loam, sandy loam, silt loam and clay loam. Conductivity values for other soil types were estimated on the basis of their similarity to the above four soil types as judged from Table 15. A basin average value was then computed considering all soils in the basin as mentioned. Its values is in inches per hour. As with MEAS KSAT, it was hoped to be indicative of either the parameter, KSAT, or the infiltration process.

(3) A measure of effective capillary potential or suction at field capacity, MEAS PS, is determined by considering mean values for the various soil types of moisture tension at field capacity, ψ_{fc}, moisture content at field capacity, W_{fc}, and saturation, W_s, as computed from the available ARS data, and the relationship for effective capillary potential, PS, which is defined as a function of capillary potential at the wetting front and the moisture content differential between saturation and field capacity conditions. This relationship has been shown during the development of equation (II.5) and can be expressed here using moisture tension data as

$$PS = \psi_{fc} (W_s - W_{fc}) \qquad (V.2)$$

in which the variables are defined above. Two assumptions were made in applying this equation to ARS data. First, moisture tension at field capacity, ψ_{fc}, was assumed to be approximately 0.1 bars (100 cms) for sandy soils, and 0.3 bars (300 cms) for most other soils. Second, saturation moisture content, W_s, was approximated by assuming that the volume of the soil voids equaled the volume of water, and, thus, moisture content at saturation, W_s, was equal to the total porosity value. Using the values of ψ_{fc}, W_s and W_{fc} for the particular soils of concern, PS was computed for each soil and the basin value, MEAS PS, was computed as indicated previously. Its value is in inches. It should be indicative of either the parameter, PSP, or the infiltration process.

(4) A measure of the ratio of effective capillary potential at wilting point to that at field capacity, where wilting point is defined as the moisture content where moisture is retained at a tension of 15 bars (15000 cms), is called MEAS RGF15B. It is determined by considering mean values for the various soil types of moisture tension at wilting point, ψ_{wp}, moisture content at wilting point, W_{wp}, and saturation, W_s, as computed from the available ARS data. The effective capillary potential at wilting point, PS_{wp}, is expressed

$$PS_{wp} = \psi_{wp} \ (W_s - W_{wp}) \tag{V.3}$$

in which the variables are defined above. The ratio of PS_{wp} to PS is referred to as MEAS RGF. As indicated, the values of ψ_{wp} and W_{wp} are for 15 bars of tension. This is the lowest moisture content value published by ARS, and at this moisture content, very few plants would survive. MEAS RGF15B is determined by computing MEAS RGF for each soil in a basin and then determining the basin average as explained previously. Its value is dimensionless, and should correlate with the Model parameter, RGF.

(5) A similar measure of the ratio in (4) is defined at a tension of 3 bars (3000 cms). MEAS RGF3B is determined in the same manner as MEAS RGF15B with the exception that ψ_{wp} and W_{wp} are for 3 bars of tension. This is the moisture content at which some plants are beginning to wilt. Its value is also dimensionless, and should be indicative of the Model parameter, RGF.

The values for these ten indices serve as an average relative measure of how these drainage basins will respond to precipitation input given the correctness of the determined soil coverage. Their application in this study is presented in a later chapter.

Climatic Characteristics

This final category of measurable basin characteristics is included to quantify the precipitation input to these sites. The sources of information are publications of the U.S. Weather Bureau (now National Weather Service). A total of three climatic characteristics were determined. These included mean annual precipitation, the 2-year, 24-hour maximum precipitation and the 50-year, 24-hour maximum precipitation. These are discussed in this section with respect to their definitions, and the manner in which they were determined. Appendix D, Table D.6, lists the actual values determined according to the identifiers included with the discussions.

(1) Mean annual precipitation, MN PRECIP, was determined for the previous studies by use of maps published in the U.S. Weather Bureau series, Climates of the States. Its value is in inches.

(2) The 2-year, 24-hour maximum precipitation, I24,2 was determined for the previous studies by use of maps available in U.S. Weather Bureau Technical Paper No. 40 (Hershfield, 1961). Its value is in inches.

(3) The 50-year, 24-hour maximum precipitation, I24,50, was determined for this study in the same manner as I24,2. Its value is also in inches.

These three characteristics are used to describe the climate for the study area in terms of precipitation. The application to this study is presented in a later chapter.

Summary

This chapter has presented the physical basin characteristics which are used in an attempt to develop relationships for predicting Model parameters. A total of 30 characteristics, neglecting soil type and composition information, were determined. The characteristics have been divided into three categories, each discussed below.

The first category was termed descriptive basin characteristics; they describe the drainage basin in terms of size, shape, length, width, and topography. A total of 17 measures were made available. In general, the accuracy of the values chosen is considered good. Although they describe the drainage basin, the values are lumped over the entire area.

However, their use for a lumped parametric model is appropriate.

The second category was termed soils characteristics; they describe the soils over the drainage basin in terms of type and composition. Soils characteristics are indices to the infiltration and moisture accounting processes. The soils were grouped according to the use of 12 specific soils types and 4 different composition classes. The determination of the percentages of total area which each soil type and composition class represented was considered to be as accurate as the soil survey maps. The resulting 10 soils indices were computed under the assumption that point values applied for soil types which were subject to natural variation. Admittedly, this is a gross simplification. However, the absence of a more complete data source for soils information necessitated such an assumption. Thus the values, although no more than representative of a lumped basin averaged index, are considered sufficient for use with this Model.

The final category was termed climatic characteristics; they describe some aspects of the general nature of the precipitation which has occurred at the drainage basin. Climatic characteristics measuring the influence on evapotranspiration were not considered due to the manner in which evapotranspiration and the Model parameter, EVC, have been treated, as explained in Chapter VI. The 3 characteristics chosen were determined from U.S. Weather Bureau (now National Weather Service) publications, and are considered sufficiently accurate.

CHAPTER VI

ANALYSIS OF CALIBRATIONS

Introduction

Initially, calibrations of the Model parameters for 344 drainage basin sites in the six state study area were available. This total was reduced to 228 sites based on the availability of soils information as explained in Chapter V. The parameter values of these 228 sites served as the source of the dependent variables which were related to the physical basin cahracteristics. Thus, the calibrations which produced these values had to be investigated to insure that the resultant parameter values would be appropriate for developing relationships with the basin characteristics. This chapter presents an analysis of these calibrations.

This analysis is presented in the following form. The first section analyzes the efficiency of the fitting technique applied and objective function form used for the calibrations. The second section documents the need for and the results of needed recalibrations. The third section explains the method used for verifying the calibrations so that they may be accepted or rejected. The fourth section explains the method used to evaluate the composition of the data set used for calibrations. The fifth section presents the results of applying the above described methods to determine a selection of drainage basins to be used in this study. The last section presents a summary for the chapter.

Analysis of Method

The three-step process for determining optimal parameter values has been detailed in Chapter II. The composition of the data set and an approach to verification of the results of this process are presented in later sections of this chapter. This section is concerned with step (2) of this process, the actual determination of the optimal parameter values. More specifically, the efficiency of the fitting technique[1/] and the objective function form are examined.

Efficiency of the Rosenbrock Optimization Routine

The requirements for an optimization scheme should include the ability to find a global optimum and to minimize the effects of parameter interaction. From a theoretical standpoint, Wilde (1964) lends credence to Rosenbrock's method for locating the optimum and explains this technique's use of the Gram-Schmidt orthogonilization process to remove the interaction between variables. The reported acceptance of parameter values produced by the Rosenbrock technique in the field of hydrologic modeling by Dawdy and O'Donnell (1965), Ibbitt (1970), and Leasvesly (1973) also supports its use. For this study, the Rosenbrock technique was compared to two other optimization routines, and evaluated for its ability to locate the optimum and remove interaction among parameters.

[1/] For this study, efficiency of the fitting technique is defined as the ability of the fitting technique to locate the global optimum with minimal effects from parameter interactions and with a minimal number of iterations.

Pattern Search, as described by Munro (1971) and the Simplex Method,[2/] as described by Johnston and Pilgrim (1973) were chosen for comparative purposes. Two test functions were chosen for the comparison and the results are presented in Table 16. From this, the relative efficiency of these techniques can be ranked as first, Simplex, second, Rosenbrock and third, Pattern Search. However, the differences between the results produced does not show an advantage in replacing the Rosenbrock technique.

As mentioned, the Rosenbrock technique is designed to locate the global optimum and to remove parameter interaction by the use of the Gram-Schmidt orthogonalization process. Table 16 shows that this technique has the capability to locate the global optimum. The practice of fitting runoff producing parameters separately from routing parameters removes the possibility for interaction between these two groups of parameters. Of course, interaction is also removed by setting parameter values and, thus, removing them from the calibration process. The effects of interacting may also be reduced by setting appropriate bounds for the parameters. However, the equations and logic used make it impossible to remove all interaction between parameters.

Appendix C, Figures C.18 through C.25, shows a typical result of parameter interaction for peak discharge from a single event. Figures C.26 through C.33 in Appendix C show a typical result of parameter interaction on the shape of the objective function value for peak

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[2/] Simplex Method is based on work by Nelder and Mead. It has been referred to as the Flexible Polyhedron Search (Himmelblau, 1972).

Table 16. Comparison of Optimization Routines

ROUTINE NAME	NO. OF ITERATIONS	DEPENDENT VARIABLE Y	INDEPENDENT VARIABLES A	B	C	D
Equation (1), $Y = 100(B - A^2)^2 + (1 - A)^2$ a/						
START		24.2	-1.20	1.00		
CORRECT		0	1.00	1.00		
ROSENBROCK	295	1.084×10^{-5}	1.005	1.0007		
PATTERN SEARCH	350	1.060×10^{-5}	1.003	1.0070		
SIMPLEX	220	5.912×10^{-12}	1.0000	1.0000		
Equation (2), $Y = \Sigma[(Ae^{-Bx_i^C}\cos(Dx_i))] - Z_i]^2$ b/						
START		.8742	1.020	1.640	2.450	2.410
ROSENBROCK	100	.0806	.980	1.459	1.278	.953
PATTERN SEARCH	100	.1375	.999	1.722	1.979	1.059
SIMPLEX	100	.0778	1.006	1.325	1.119	.998

a/ Equation from Wilde (1964).

b/ Equation from Munro (1971).

discharges (equation II.15) at a site. These examples of interaction show that the more sensitive parameters, when incremented in concert with another sensitive parameter, will exhibit greater effects of interaction than if the parameter of concern was incremented with one of low sensitivity.

In order to make a judgment on how the Rosenbrock technique handles the determination of optimal parameter values in terms of locating the optimum parameter set and accounting for the problem of interaction, a series of tests were performed on an error free input and output data set as explained by Dawdy and O'Donnell (1965).[3/] Only the sensitive parameters from the infiltration component, PSP, KSAT, RGF and BMSM were used. These parameters appear in the equation (IV.1) representing infiltration rate. The objective function used was that shown as OF_3, equation (II.15), and expressed as percent. The results of these tests are presented in Table 17.

Table 17 shows that the Rosenbrock technique locates the optimum parameter set relatively quickly as shown by the results of using only 10 interactions per parameters. Cases A and B illustrates the results of the fit for all four of the parameters where, in Case A, they are all set initially at values twice that of the optimums, and, in Case B, they are all set initially at values one-half that of the optimums.

[3/] A complete input data time series was selected. All ten parameters were assigned values. The Model was operated with this input and parameter set to produce an output data time series. This output was then considered to be the "observed" data and the selected Model parameters were assigned new initial values and redetermined with the Rosenbrock technique.

Table 17. Results Using the Rosenbrock Technique for an Error-Free Data Set

Case		Iterations Per Parm	PSP	KSAT	RGF	BMSM	OBJ FUNC. Value, Percent
OPTIMUM			5.00	.025	15.5	5.00	0
A: ALL PARMS ABOVE OPTIMUMS; FIT ALL							
		10					
Start			10.00	.050	31.00	10.00	> 100
(1)	ORDER		1st	2nd	3rd	4th	
	END		5.253	.023	16.456	5.208	1.4
(2)	ORDER		2nd	1st	3rd	4th	
	END		5.282	.024	16.982	5.147	3.4
(3)	ORDER		3rd	4th	2nd	1st	
	END		5.769	.025	16.84	5.004	13.5
B: ALL PARMS BELOW OPTIMUMS; FIT ALL							
		10					
Start			2.50	.012	7.80	2.50	93.5
(1)	ORDER		1st	2nd	3rd	4th	
	END		5.504	.026	13.067	5.183	2.2
(2)	ORDER		2nd	1st	3rd	4th	
	END		5.273	.025	13.173	5.209	6.1
(3)	ORDER		3rd	4th	2nd	1st	
	END		4.140	.020	22.754	4.213	9.0
C: FIT PSP AND KSAT; BMSM and/or RGF SET DIFFERENT THAN OPTIMUM							
		10					
(1)	START		2.50	.010	15.5	10.0	82.6
	END		7.875	.017			33.4

Table 17. continued

Case		Iterations Per Parm	PSP	KSAT	RGF	BMSM	OBJ Func. value, Percent
(2)	START		2.50	.010	15.5	2.50	77.1
	END		7.50	.016			33.5
(3)	START		2.50	.010	7.75	2.50	> 100
	END		7.875	.017			29.7
D: FIT PSP AND KSAT; ALL OTHERS AT OPTIMUMS							
		10					
(1)	START		25.0	.010	15.5	5.00	42.7
	END		16.0	.008			3.1
(2)	START		15.0	.050	15.5	5.00	> 100
	END		8.303	.016			2.2
E: FIT RGF AND BMSM; ALL OTHERS AT OPTIMUMS							
		10					
(1)	START		5.00	.025	31.00	10.00	45.6
	END				17.20	5.24	3.6
(2)	START		5.00	.025	31.00	2.50	78.0
	END				19.60	5.54	9.8
(3)	START		5.00	.025	7.75	2.50	30.9
	END				15.09	4.89	2.6
(4)	START		5.00	.025	7.75	10.00	43.9
	END				16.70	6.22	9.8
F: FIT RGF ONLY; ALL OTHERS AT OPTIMUM							
		10					
(1)	START		5.00	.025	31.00	5.00	39.5
	END				15.90		1.4
(2)	START		5.00	.025	7.75	5.00	31.4
	END				15.64		1.3

Table 17. continued

Case		Iterations Per Parm	PSP	KSAT	RGF	BMSM	OBJ FUNC. value, Percent
G: FIT BMSM ONLY; ALL OTHERS AT OPTIMUM							
		10					
(1)	START		5.00	.025	15.50	10.00	34.0
	END					5.13	1.7
(2)	START		5.00	.025	15.50	2.50	34.7
	END					5.01	1.4

The results show that this technique yields values very close to the actual optimums. Only the difference in order of parameters subject to calibration appears to make a difference in the results. Cases A (3), and B (3) represent the least sensitive order of parameters which does show that the parameter sensitivity does affect the speed of the fit.

One might erroneously conclude from Cases A and B that interaction between parameters has been eliminated since all the parameters approach their optimum. However, Cases C and D show that this is not correct. Case C starts with PSP and KSAT set initially at approximately one-half their optimums and either RGF or BMSM or both set at values other than their optimums. Fitting PSP and KSAT show that that the PSP final value is above its optimum while that of KSAT is below its optimum. Case D, with RGF and BMSM set at their optimums, shows the same result. for PSP and KSAT. An interesting point is that both cases show that the product of PSP and KSAT does approach the product of the optimum values of PSP and KSAT. Thus, it is concluded that the Rosenbrock technique does not necessarily yield individual optimum values for PSP and KSAT, but more likely yields values for PSP and KSAT such that their product, PSP * KSAT, is optimum.

Cases E, F, and G are concerned with the results of fitting RGF and BMSM either together or separately, while PSP and KSAT are set at their optimums. Case E is of most interest because it indicates that RGF and BMSM do not exhibit the amount of interaction shown by PSP and KSAT as the values determined for RGF and BMSM, for all examples, closely approximate their optimums. It is concluded from the results for this case and those of Cases A and B that RGF and BMSM do not interact with each other or with PSP and/or KSAT on the same identifiable scale as PSP interacts with KSAT.

The analyses of Table 17 illustrate a basis for appreciating the parameter values which the Rosenbrock technique locates. First, this technique does approach the global optimum with very reasonable speed as shown by the use of only 10 iterations per parameter to closely approximate the optimum values. This speed can be increased by applying the Rosenbrock technique on the parameters in order of their sensitivity. Second, the Rosenbrock technique accounts for interaction either by removing its effects as in the determination of RGF and BMSM or by seeking an optimal effect of the interaction as with PSP x KSAT.

The performance of the Rosenbrock technique was also viewed on a sample of sites using observed data. Four of the test sites selected in Chapter IV were chosen. These sites, stations 02192400, 02488540, 0558050, and 06909700, had the most complete data sets with respect to number and variety of events. Using the method for varying parameters discussed in Chapter IV, objective function values, equation (II.15), were computed at each of these sites for individual parameters and logical pairs of parameters.[4/] Kendall's coefficient of concordance (Kendall, 1955) was computed by considering the observers doing the

[4/] Logical pairs of parameters are defined as those that can be made by considering the Model as two parts, the runoff producing portion and the routing portion. Thus, the seven parameters of the runoff producing portion yield 21 pairs and the three parameters of the routing portion yield 3 pairs.

ranking to be the individual parameters or pairs and considering the individuals being ranked to be the objective function value at the various values of the parameters as represented by their proportion to the fitted parameter value. The results showed that the optimum remained at the calibrated value for three of the four sites. The fourth site, 06909700, was found to have an objective function value for the calibrated parameter set within 15% of the minimum. This value is deemed acceptable, and it is concluded that the Rosenbrock technique has converged on an acceptable value of the optimum for these sites.

This discussion has shown that the Rosenbrock technique compares favorable with two other optimization routines, handles interaction sufficiently, and locates the optimum with reasonable speed and consistency. Thus, it is concluded that the Rosenbrock technique serves as an acceptable optimizing routine for determining parameter values for this Model.

Validity of Objective Function Form

The objective functions used to calibrate the Model were presented as equations (II.13), (II.14) and (II.15). The form used can be expressed as

$$OF = \sum_{1}^{\#FE} [LOG(O_C) - LOG(O_O)]^2 \qquad (VI.1)$$

where OF is the value to be minimized, #FE is the total number of storm events, O_C refers to output computed by Model and O_O refers to the corresponding observed output.

It was assumed that the validity of this objective function form would be established if this form was shown to be the equal or superior to other forms, and if the outputs entering the form were consistent with the purposes of the Model.

The outputs of the Model which enter the objective function are (1) storm runoff volumes, in equation (II.13), (2) storm peak discharges corrected for erroneous volumes in equation (II.14) and (3) storm peak discharges in equation (II.15). These choices are logical as the Model's intended purpose is to predict storm runoff volumes and the associated peak discharges. The choices are also consistent in their application since (1) the storm volumes are used to determine the runoff producing parameters, (2) storm peaks corrected for erroneous volumes are used to determine the routing parameters, and (3) storm peak discharges are used to readjust the runoff producing parameters once the routing parameters have been determined.

In order to determine whether or not this objective function form was equal to or superior to others, four other forms were selected. Using the same definitions as in equation (VI.1), these are expressed as:

$$OF_A = \sum_{1}^{\#FE} (O_C - O_O)^2 \qquad \text{(VI.2)}$$

$$OF_B = \sum_{1}^{\#FE} (O_C^{\,2} - O_O^{\,2})^2 \qquad \text{(VI.3)}$$

$$OF_C = \sum_{1}^{\#FE} |O_C - O_O| \qquad \text{(VI.4)}$$

and

$$OF_D = \sum_{1}^{\#FE} \left(\frac{O_C - O_O}{O_O}\right)^2 \tag{VI.5}$$

These forms were examined to determine which form would best serve the purpose for this study. The sensitivity studies showed that the more varied a range of storm events present in the data set, the more likely the parameters would be determined properly by the calibration process. This implies that the calibration process must not be biased toward storm events of a particular range, i.e., the parameters should not be determined by an objective function form which is heavily influenced by one particular range. These objective function forms were judged on this basis.

Table 18 shows a comparison of how the values for these forms vary over a range of output values. Figures C.34 through C.43 in Appendix C illustrate the resulting shapes of the objective functions for these forms when each parameter value is varied. An analysis of the differences between the sample objective function values shown indicate the square transform, OF_B, places the greatest amount of weight on larger outputs with little significance given the relative size of the difference between O_C and O_O. The remaining four forms reflect the difference between the computed and observed. Of these, the objective function form chosen, OF, and the sum of relative differences squared, OF_D, insure that the difference between the computed and observed is weighted on the basis of the relative size of this difference. This

Table 18. Comparison of Objective Function Forms

Test			VALUE OF OBJECTIVE FUNCTION				
No.	O_c	O_o	OF	OFA	OFB	OFC	EFD
1	90	100	.00209	100	3.61×10^6	10	.01
2	9	10	.00209	1	361	1	.01
3	110	100	.00171	100	4.41×10^6	10	.01
4	11	10	.00171	1	441	1	.01
5	180	200	.00209	400	5.77×10^7	20	.01
6	220	200	.00171	400	7.05×10^7	20	.01
7	80	100	.00939	400	1.297×10^7	20	.04
8	120	100	.00627	400	1.936×10^7	20	.04
9	50	100	.0906	2500	5.625×10^7	50	.25
10	100	50	.0906	2500	5.625×10^7	50	1.00
11	20	10	.0906	100	9.0×10^4	10	1.00
12	10	20	.0906	100	9.0×10^4	10	.25

means that the use of OF and OF_D will reduce percentage differences between observed and computed output regardless of the size of the output. Table 18 shows the difference between these two forms. Test number 7, 8 and 9 show that OF, in an attempt to reach an overall minimum, will tend to change the ratio, computed by dividing the observed output by computed, to a value equal one. Test number 9 and 10 show that OF_D will tend to decrease the relative size of the difference between computed and observed with respect to the size of the observed output to reach an overall minimum. The result of this can be shown in Appendix C by Figure C.34 which shows that the optimal PSP value for OF is different than that for OF_D. Thus, while both of these weight the error in terms of its relation to the size of the output, they might yield differing answers. The choice between them appears to be subjective.

Thus, the objective function form chosen has been shown to meet the purposes of the Model and to be superior or equal to the other forms investigated.

Recalibration of Available Sites

The calibrations available for the six state study region had to be assessed for suitability to this study. Primarily, the need for recalibration was necessitated as the calibrations available for each state in the study region were performed at different times. Differences in assumptions made by individuals performing the calibrations for each of these states and changes in computer programming code for the Model had to be considered. Thus, the calibrations for all six states had to be on a common basis to be used in this study.

The only major difference between the calibrations from the six states is the manner in which values for four parameters were determined. These four parameters, DRN, EVC, RR and TP/TC, were mentioned in Chapter IV with respect to their sensitivity and requirements regarding upper bounds to their respective values. The determination of these parameters on a common basis is discussed in the order shown above.

(1) DRN can have a lower bound of greater than zero and an upper bound of less than or equal to 1.0 as it is a proportion of KSAT. It was chosen equal to 1.0, which means that no difference is shown for hydraulic conductivity in the nonsaturated and saturated sections. The insensitivity exhibited by DRN allows the effects of this value to be minimal.

(2) EVC is a coefficient to convert pan evaporation data to potential evapotranspiration data. A value was selected for a site by computing the annual average value for Class A pan evaporation at the evaporation data site selected for use at this site. Assuming lake evaporation approximates potential evapotranspiration, an average annual lake evaporation value was selected for a drainage basin site by use of the map provided in U.S. Weather Bureau, Technical Paper No. 37 (Kohler et al., 1959). EVC was determined as the ratio of this average annual lake evaporation value divided by the annual average value for pan evaporation from the selected evaporation data site. The values of EVC determined in this manner ranged from around 0.6 to 0.9.

(3) RR represents the amount of daily rainfall allowed to infiltrate. It was not allowed to exceed 1.0 unless the daily rainfall was

not representative of the amount which fell on the basin. Assuming that the daily rainfalls used with these calibrations were representative, it was felt this value should be less than 1.0. RR was arbitrarily selected as 0.85. This value was an approximate midrange value for a number of the available calibration for which RR had been determined.

(4) TP/TC represents the ratio of the time to peak to the time of concentration for the triangular translation hydrograph. Several investigators (O'Kelly, 1955, Mitchell, 1972) have alluded to this relationship and have suggested that the time to peak is approximately one-half the time of concentration. Thus, TP/TC was set equal to 0.50.

Recalibrations were necessitated if these four parameters were not set in the above manner. Complete recalibration was not always required if the previous calibration had determined values approximating the values set by this procedure for DRN, EVC, RR and TP/TC. In some instances, recalibration was performed if the previous calibration did not consider all the data available at a site due to an arbitrary screening process.

The final parameter values used in this study are presented in Appendix D, Table D.7. While there are 228 sites available, 237 are present in this table which includes 9 sites used with the split sampling method. The values are shown for only the parameters for which an attempt will be made to develop a relationship with physical basin characteristics. Thus, the parameters, DRN, EVC, RR and TP/TC, are excluded, and the calibrated parameter values for PSP, KSAT, RGF, BMSM, KSW and TC are included.

Method for Verification of Calibrated Parameters

Verification of the calibrated parameters is required as the last step of the calibration process. It is also necessary for this study as a check on recalibration and as a means to insure that the parameter values used to develop relationships with physical basin characteristics are meaningful. In this context, meaningful is defined from a practical viewpoint, i.e., if the parameters can be verified according to a logical procedure then they are considered to be meaningful. It should be noted that individual parameters were not verified but rather the complete 6 parameter set at a site was subject to verification. Thus, if the complete set was considered to be verified, then each indivdual parameter was so considered.

The logical approach to verification adopted for this study encompasses the comparison of the resulting objective function values for the various phases of the fit, volumes, routing and peak discharges, with standards, determined from the sites available, and a statistical analysis on the comparison of the observed and simulated peak discharges. This section will explain this approach in detail. A later section will show the results of applying this approach to select sites whose parameters are felt to be appropriate for developing relationships with physical basin characteristics.

As mentioned previously, the calibration process entails fitting the parameters over three phases. The runoff producing parameters, PSP, KSAT, RGF and BMSM, are initially fit based on volumes to reduce the volume error, equation (II.13). The routing parameters, KSW and

TC, are fit to the peak discharges adjusted for correct storm volumes to reduce routing error, equation (II.14). Once the routing parameters are determined, the runoff producing parameters are "fine tuned" by fitting the observed peak discharges, i.e., total error (equation II.15). One form of verifying a site's calibration is simply to compare the values for these errors computed in the calibration with some standards. These errors can be expressed as percents.[5/] Dawdy et al. (1972) contend that an accuracy of about 30 percent for the total error is obtainable. The standards used in this study were established by analyzing the results of the 237 calibrations shown in Table D.8 of Appendix D. The mean, $\bar{x}$, and standard deviation, s, were computed for the error values. The results are as follows:

VOLUME: $\bar{x}$ = 53.84%, s = 24.14%.

ROUTING: $\bar{x}$ = 28.10%, s = 12.51%.

TOTAL: $\bar{x}$ = 48.75%, s = 22.77%.

These values were used to establish the standards which are as follows:
(1) VOLUME error is considered to be acceptable if its value is less than or equal to 40%, and conditionally acceptable if its value is less than or equal to 50%.
(2) ROUTING error is considered to be acceptable if its value is less than or equal to 40%

[5/] See footnote no. 12, Chapter II.

(3) TOTAL error follows the same guidelines as shown for VOLUME error. A site was acceptable with respect to errors if TOTAL error was acceptable and either VOLUME or ROUTING error was acceptable. It was found, as indicated by the statistics, that the ROUTING error was almost always within the acceptable range, and that TOTAL error and VOLUME error were highly correlated as might be suspected since the same parameters are fit during these phases.

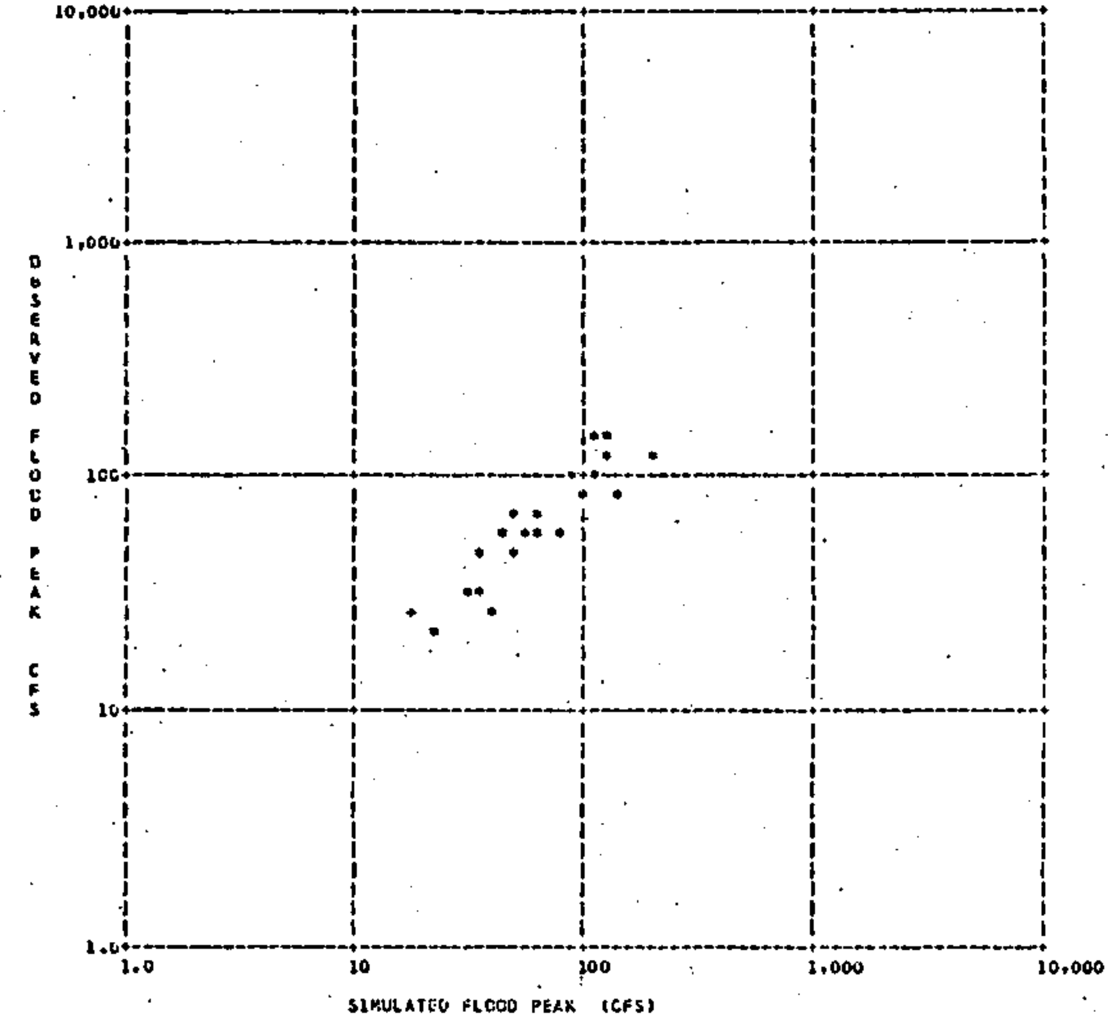
Another measure of TOTAL error is a view of the relationship between the observed peaks versus simulated peaks. Figure 10 shows a typical scatter diagram. It is apparent that the relationship shown by this type plot can be represented by an equation in the form,

$$Y = A + BX \tag{VI.6}$$

where Y is the logarthmic transformed value of observed peak discharge, A is the intercept on the ordinate, B is the slope of the straight-line relationship, and X is the logarthmic transformed value of the simulated peak discharge. The value for A and B can be determined by applying the least squares method which has been shown to produce the following relationships

$$B = \frac{\sum_{i=1}^{\#FE} X_i Y_i - n\overline{XY}}{\sum_{i=1}^{\#FE} X_i^2 - n(\overline{X})^2} \tag{VI.7}$$

USGS RAINFALL-RUNOFF MODEL CALIBRATION FOR 02189030 STEPHENS CRK TRIB AT CARNESVILLE, GA



NUMBER OF POINTS PLOTTED = 22
NUMBER OF MULTIPLE POINTS = 1
NUMBER OF POINTS OFF GRID = 0
NUMBER OF POINTS OMITTED = 0

*** NOTE ***
PLOT ROUTINE EXCLUDES
POINTS NOT INCLUDED
IN CALIBRATION

Figure 10. Plot of Observed Flood Peaks versus Simulated Flood Peaks

and $A = \overline{Y} - B\overline{X}$ (VI.8)

where X_i is the log transformed value of an individual storm event computed peak, Y_i is the log transformed value of the individual storm event observed peak, $\overline{X}$ and $\overline{Y}$ are the respective mean of logs and n is the sample size.

Comparison between the two separate data series can be made based on their respective means and variances, on the correlation coefficient and the coefficients of the linear relationship depicted in equation (VI.6), the intercept and slope. Carrigan and Dempster suggested the use of statistical tests on the correlation coefficient, means and the slope, B of equation (VI.6), as an aid for judging the calibrations required by the USGS-FHA program. This study applied these measures and also used similar tests on the variances and the intercept, A, of equation (VI.6).

Both series of logarithmic transformed peak discharges, computed and observed, may be described by their means and variances. The correlation coefficient, which is computed by considering the observed discharge and the corresponding computed discharge produced by the Model for each storm event in the calibration, shows agreement between these two series. Both series of transformed peaks are assumed to have a normal distribution. The means, variances and correlation coefficient are tested using standard statistical tests.[6/]

[6/] Benjamin and Cornell (1970), pp. 415-418.

The means of the two series were tested for equality. A comparison of the mean of log transformed observed peak, $\overline{Y}$, with the mean of log transformed simulated peaks, $\overline{X}$, was done by the use of a Student t-test where the test statistic, t_s, was defined as

$$t_s = (\overline{X} - \overline{Y}) \Big/ \sqrt{\frac{S_x^2 + S_y^2}{n}}$$

where S_x^2 and S_y^2 are the respective variances, and n is the sample size. The test was performed with the level of significance, α, set at five and ten percent. The null hypothesis, H_o, is defined as

$$H_o : \overline{X} = \overline{Y}$$

where H_o is accepted if $-t_{1-\alpha/2,2n-2} \leq t_s \leq t_{1-\alpha/2,2n-2}$.

The variances of these transformed observed and simulated peaks were, also, tested for equality. These variances were compared using a F-test where the test statistic, F_s, was given by the ratio of the respective variances, S_x^2 and S_y^2. The level of significance was five persent. The null hypothesis is defined as

$$H_o : S_x^2 = S_y^2$$

where H_o is accepted if $F_{\alpha/2,n-1,n-1} < F_s < F_{1-\alpha/2,n-1,n-1}$.

The two series were tested for lack of correlation. Since the observed transformed peaks and the computed transformed peaks are assumed to be jointly normally distributed, the correlation coefficient, $R_{x,y}$ is given by

$$R_{x,y} = \frac{1}{n} \frac{\sum_{i=1}^{n} (X_i - \overline{X})(Y_i - \overline{Y})}{S_x S_y}$$

where n, $\overline{X}$, $\overline{Y}$, S_x, S_y, X_i and Y_i are defined above. A Student t-test is performed to test whether or not the correlation coefficient is not zero using a test statistic, t_s, defined as

$$t_s = \frac{R_{x,y} \sqrt{n-2}}{\sqrt{1 - R_{x,y}^{\;2}}}$$

where the test was performed at the five and ten percent level of significance. The null hypothesis is defined as

$$H_o: R_{x,y} = 0.0$$

where H_o is accepted if $-t_{\alpha/2,n-2} \leq t_s \leq t_{\alpha/2,n-2}$.

The results of the statistical tests on the means, variances and correlation coefficient were used as information in judging the acceptance of a calibration. Acceptance of the null hypothesis for either the equality of the means, $\overline{X}$ and $\overline{Y}$, or the equality of the variances, $S_x^{\;2}$ and $S_y^{\;2}$, was considered a positive point toward accepting a calibration. Rejection of the null hypothesis for the correlation coefficient equal zero was considered a positive point toward accepting a calibration.

The coefficients of the linear relationship in equation (VI.6) were subjected to similar standard statistical tests.[7/] The slope, B, was tested using a Student t-test. The test statistic was the value of B. The levels of significance were five and ten percent. The null hypothesis is defined as

$$H_o: B = 1$$

where H_o is accepted if $1.0 - t_{\alpha/2,n-2} * S_B \leq B \leq 1.0 + t_{\alpha/2,n-2} * S_B$ where S_B is the standard deviation of B.[8/] Acceptance of the null hypothesis ruled out a bias in prediction of peak discharges by the Model, and was considered as a positive point toward acceptance of the calibration. The intercept, A, was also tested using a Student t-test. The test statistic was the value of A. The levels of significance were five and ten percent. The null hypothesis is defined as

$$H_o: A = 0$$

[7/] Benjamin and Cornell (1970), pp. 419-440.

[8/] The standard deviation of B, S_B, is given as

$$S_B = \sqrt{\frac{S_y^2 \, (1 - R_{x,y})^2}{S_x^2 \, (n-2)}}$$

where S_y^2, S_x^2, $R_{x,y}$ and n are defined above.

where H_o is accepted if $-t_{\alpha/2,n-2} * S_A \leq A \leq t_{\alpha/2,n-2} * S_A$ where S_A is the standard deviation of A.[9] Acceptance of this null hypothesis was also considered a positive point toward acceptance of the calibration.

The results of these statistical tests on means, variances, correlation coefficient and the coefficients of the linear relationship in equation (VI.6) were applied based on the following considerations. First, the slope, B, can be shown to be a function of the correlation coefficient and the variances as equation (VI.7) can be expressed as

$$B = \frac{R_{x,y} S_y}{S_x} \tag{VI.9}$$

Second, the intercept, A, has already been shown in equation (VI.8) to be a function of the means, $\bar{X}$ and $\bar{Y}$ and the slope, B. Thus, a site was considered acceptable with respect to its calibration if the t-tests on both A and B showed the acceptance of the null hypothesis at the higher level of significance. However, if one of these was acceptable at only the lower level of significance, then the other appropriate measures were evaluated. For the slope, B, a site was not acceptable

[9] The standard deviation of A, S_A, is given as

$$S_A = \sqrt{S_B^{\,2} \, (S_x^{\,2} + \bar{X}^{\,2})}$$

where S_B is defined in footnote No. 8 of this chapter and $S_x^{\,2}$ and $\bar{X}$ are defined above.

unless the null hypothesis for $R_{x,y}$ was rejected and the null hypothesis for the variance, S_x^2 and S_y^2, was accepted. The intercept, A, was considered acceptable for this case if the null hypothesis for the means, $\bar{X}$ and $\bar{Y}$, was accepted and the null hypothesis for the slope, B, was acceptable. Rejection of the null hypothesis for the slope and/or intercept at both levels of significance meant that the calibration for the site was not acceptable. Table 19 summaries the possible results of these statistical tests at a site and the corresponding decision reached on the site calibration.

This section has defined verification of a calibrated parameter set with two criteria. The first requires that the error measure values are below certain standards. The second requires the calibration to be acceptable on the basis of statistical tests on measures of the relationship between observed and computed data. The application of these two criteria are presented in a later section of this chapter in order to determine a set of drainage basin sites whose parameters are suitable for inclusion in the development of parameter versus basin characteristic relationships. Appendix D, Table D.8, presents a listing of the error measures, means, variances, correlation coefficient and the coefficients of equation (VI.6) required to apply this criteria.

Method for Analysis of Data Set Composition

As mentioned in Chapter II, the composition of the data set will have an effect on the Model parameters. Chapter IV showed that the sensitivity of the Model parameters varied over the range of storm events. This was particularly true of the runoff producing parameters

Table 19. Summary of Decision Process for Site Calibration Selection Based on Results of Statistical Tests between Observed and Simulated Peak Discharges

ITEM	NULL HYPOTHESIS, H_o	POSSIBLE RESULTS AT A SITE							
I. Test performed on:		1	2	3	4	5	6	7	8
Intercept, A	$A = 0$	AH	AH	AH	AL	AL	AL	AL	R and/or
Slope, B	$B = 1$	AH	AL	AL	AH	AH	AL	AL	R
Means, $\bar{X}$ and $\bar{Y}$	$\bar{X} = \bar{Y}$				AL	R	AL	R and/or	
Variances, S_x^2 and S_y^2	$S_x^2 = S_y^2$		A	R and/or			A	A and/or	
Corr. Coef., $R_{x,y}$	$R_{x,y} = 0$		R	A			R	R	
II. Decision on Site Calibration		A	A	R	A	R	A	R	R

Key:

A - Accept without concern for level of significance.
AH - Accept null hypothesis at higher level of significance.
AL - Accept null hypothesis at lower level of significance only.
R - Reject.

of concern, PSP, KSAT, RGF, and BMSM. Also, as this sensitivity changed so did the relative importance of the parameters. Thus, the routing parameters of concern, KSW and TC, while remaining fairly constant in terms of a sensitivity measure, increased in relative importance for controlling Model output for larger storm events due to the decreased sensitivity of the runoff producing parameters.

For this study, the importance of data set composition is the influence it has on the calibrated Model parameters. This influence stems from parameter sensitivity. Thus, the parameter value can not be regarded as valid if the data set was not composed of a sufficient variety of storm events. For this reason, an attempt was made to evaluate the data set composition. Five categories of storm event types, used previously in Chapter IV, were used here. Two of these can be classified as basin response measures. These are the ratio of storm runoff volume to storm rainfall, RØ/RF, and the ratio of peak discharge to drainage area, Q/DA. The remaining three can be classified as model input measures because they are measures of the precipitation data used as input to the Model. These are average daily storm precipitation, AVE PRECIP, antecedent moisture index, AMI, and the three hour storm intensity factor, SIF 3HR. These five categories were then defined as occurring at the three levels, HIGH, MED, and LOW, shown previously in Table 6. Since the bounds for these levels were based on the 189 storms of the test sites, the 33rd percentile and 67th percentile values were determined for the 4504 storms of the total set of 228 sites. Table 20 shows the comparison of these values. Only

Table 20. Comparison of Bounds between Class Intervals for Test Sites and Total Sample

Storm Event Class	Test Sites	Total Sample
RØ/RF:		
HIGH	> .45	> .44
MED	.25 ≤ RØ/RF ≤ .45	.23 ≤ RØ/RF ≤ .44
LOW	< .25	< .23
Q/DA:		
HIGH	> 250	> 134
MED	75 ≤ Q/DA ≤ 250	49 ≤ Q/DA ≤ 134
LOW	< 75	< 49
AVE PRECIP:		
HIGH	> 2.00	> 1.35
MED	1.25 ≤ AVE PRECIP ≤ 2.00	.82 ≤ AVE PRECIP ≤ 1.35
LOW	<1.25	< .82
AMI:		
HIGH	> 1.25	> 1.25
MED	.50 ≤ AMI ≤ 1.25	.58 ≤ AMI ≤ 1.25
LOW	< .50	< .58
SIF 3HR:		
HIGH	> 1.80	> 1.63
MED	1.20 ≤ SIF 3HR ≤ 1.80	1.04 ≤ SIF 3HR ≤ 1.63
LOW	<1.20	< 1.04

the bounds for two of these classes, Q/DA and AVE PRECIP, are shown to be quite different. As the sensitivity study was done using bounds shown under the heading, "test sites", in Table 20, it was decided to continue their use here because the results of the sensitivity study are applied.

The following three assumptions were made for this method of analyzing data set composition. First, the data set used to calibrate the three parameters, PSP, KSW, and RGF, which showed high sensitivity to storm events classified in the LOW interval, must contain storm events in this interval. Second, the data set used for BMSM must contain storm events of all intervals, HIGH, MED and LOW, so that the range of moisture conditions can be modeled. Third, the data set for KSW and TC should especially contain storm events classed in the HIGH interval.

The method incorporated these assumptions by arbitrarily establishing a desired distribution of storm events within each of these three levels for all five classes. Then the number of storm events per each one of these intervals was determined for all five classes at each of the 228 sites. The Chi-square test for goodness of fit[10/] was then applied to each of the five classes to determine whether or not the distribution of storm events used for a calibration at a site was the same as the distribution of storm events desired. This test

[10/] Conover, W. J., (1971), pp. 186-195.

was performed at the five and ten percent level of significance. A site was considered acceptable if it could show that the distribution of its storm events with respect to basin response measures and model input measures was equivalent to the distribution desired. Acceptance was not dependent on the acceptance of all classes. Instead, the data set was considered acceptable with respect to basin response if it was acceptable for either RØ/RF or Q/DA. Likewise, the data set was considered acceptable with respect to model input if it was acceptable for either AVE PRECIP or SIF 3HR. If acceptable for only the lower level of significance for AVE PRECIP or SIF 3HR, it was considered acceptable for model input if it was acceptable for AMI.

This method of applying a statistical test to determine whether or not the actual distribution of storm events at a site is the same as the distribution of storm events assumed necessary for parameter calibration is used in the following section. Two different distributions for storm events were arbitrarily established. The first assumed that each interval, HIGH, MED and LOW, must contain an equal number of storm events. The second was slanted toward the higher events and required desired frequencies of 0.45 of total as HIGH, 0.30 as MED and 0.25 as LOW. Table D.9 in Appendix D presents the composition of these data sets for HIGH, MED and LOW intervals of each storm event class for the 228 sites.

Selection of Sites for Developing Relationships between Parameters and Basin Characteristics

This section presents the selection of sites for which parameter values were used to develop relationships between the Model parameters and the basin characteristics. The methods of the last two sections were applied to produce this selection with one exception, no sites were considered which were fit on 5 or less storm events. These methods defined selection as a result of accepting the results of applying the criteria for error measure, for calibration and for composition of the data set. Accepting these results is dependent on the standards imposed in the methods. These standards were varied with respect to the error measure and data set composition. The standards for error measure were 40 percent for each of the errors (VOLUMES, ROUTING and TOTAL) during one selection and 50 percent for VOLUMES and TOTAL errors with ROUTING remaining at 40 percent for another selection. The standard for data set composition was changed by using the two different distributions indicated in the previous section. The selection process was also varied by allowing a site to be chosen if it was acceptable according to all three criteria, errors, calibration and data set composition for one selection and if it was acceptable to only two of these criteria for another selection.

In order to reduce the number of selections required by the above variations, the most lenient and most strict selections were made using the different distributions for data set composition. Thus, for each proposed distribution of data set composition, a station was selected if any two of the following three criteria were accepted. First, errors were considered acceptable using the previously outlined procedure and the standard for VOLUME and TOTAL errors was

50 percent and the standard for ROUTING error was 40 percent. Second, the calibration was judged acceptable by the previously outlined method. Third, the composition of the data set was such that the frequency of HIGH, MED and LOW storm events was equivalent to the frequency desired. This is the more lenient selection. The strict selection required all three of the criteria to be accepted if a site was to be accepted. While the definitions of the second and third of these remain the same as for the more lenient selection, the first criterion regarding error standards required all standards to be equal to 40 percent.

Referring to the different distributions of the data set composition as "A" for the equal distribution for each interval[11/], and "B" for the distribution skewed towards the higher storm events[12/], the total number of calibrations which were selected by these processes are 124 by lenient A, 116 by lenient B, 36 by strict A, and 35 by strict B. Comparison of the two data set composition distributions showed that 109 of the sites selected under lenient conditions were common to both A and B, while 28 of the sites selected under the strict conditions were common to both A and B. Due to this close association, data set composition assuming equal distribution for each interval was chosen as the basis for applying the criteria with regard to data set

[11/]Probability of a storm event being classified as HIGH, MED and LOW equals 1/3.

[12/]Probability of a storm event being classified as HIGH equals 0.45, MED, 0.30, and LOW, 0.25.

composition. As a result, the final site selections are lenient A and strict A. They are referred to in the remainder of this study as LARGE and SMALL respectively. Table 21 presnets a list of these selected sites for the LARGE sample and indicates which ones of these are members of the SMALL sample.

Summary

The purpose of this chapter was to present an analysis of the calibrations available and apply this analysis in order that sites could be selected for the development of relationships between the parameters and the physical basin characteristics. The optimization routine, the Rosenbrock technique, and the objective function form used in the calibration were investigated and shown to be satisfactory in comparison to other similar fitting routines and error measure forms. The potential for interaction between PSP and KSAT was illustrated. The need for recalibrations was explained as the values for parameters DRN, EVC, RR and TP/TC were defined. These calibrations were then analyzed in terms of their error values, validity of the calibration, and adequacy of the data set. The parameter sets for sites whose calibrations passed the selection process were available for developing the relationships for which this study was undertaken. Thus, two samples of sites are available for the purpose of relating PSP, KSAT, RGF, BMSM, KSW and TC to basin characteristics. These samples contain parameter sets for these six parameters from 124 calibrations in the LARGE sample and 36 calibrations in the SMALL sample. The following

Table 21. Lists of Sites Selected for the Development of Relationships, and Designated as Sample "LARGE"

Site ID	Sequence No.*	Member Sample Small
ALABAMA		
02365310	5	Yes
02437800	20	
02451750	25	
02453900	26	
02462600	27	
03574405	31	
GEORGIA		
02189020	33	
02191270	35	
02191280	36	Yes
02191750	38	Yes
02192300	39	Yes
02192400	40	Yes
02201110	43	
02202950	47	
02216610	51	
02217250	52	Yes
02217400	53	Yes
02218100	55	Yes
02223700	56	
02225330	58	
02315980	59	Yes
02316260	61	
02317710	62	
02317760	63	Yes
02317770	65	
02317775	66	
02317795	68	
02317905	70	
02318015	72	
02318020	73	
02327350	74	
02327400	75	
02346193	76	
02346210	77	
02346217	78	
02381900	82	
02382800	83	
02382900	84	
02383000	85	Yes
GEORGIA continued		
02387300	86	
02387800	89	
02388200	90	
02397750	92	
03566660	93	
03566687	94	
ILLINOIS		
03338100	95	Yes
03344250	96	Yes
03380300	97	
03380450	98	Yes
03381600	99	Yes
03382025	100	Yes
05418800	101	
05438850	103	
05448050	105	Yes
05469750	106	
05495200	107	Yes
05502120	108	Yes
05527050	109	
05555400	114	Yes
05558050	116	Yes
05558075	117	
05577520	120	
05591500	124	
05594200	125	Yes
05596100	127	Yes
MISSISSIPPI		
02429980	129	
02447340	135	
02475220	136	
02477090	137	
02481505	140	Yes
02485780	141	
02485900	142	
02488550	145	
02489030	147	
07029252	149	Yes
07267200	150	

Table 21. continued

Site ID	Sequence No.*	Member Sample Small	Site ID	Sequence No.*	Member Sample Small
MISSISSIPPI continued			TENNESSEE		
07277550	151		03313600	193	
07282300	152		03313620	194	Yes
07287140	154		03418900	195	
07287520	155	Yes	03420360	196	
07289640	157		03420380	197	Yes
07290220	158		03420400	198	
07294400	161	Yes	03431580	201	Yes
07375235	163		03431600	202	
07376665	164		03431650	203	
			03435020	204	Yes
MISSOURI			03469110	208	
05502700	167		03486225	209	
05503000	168		03519610	210	
06815550	169		03519650	213	
06816000	170		03535140	214	
06907200	175		03538900	217	
06908300	176		03597400	220	Yes
06919200	180	Yes	03597450	221	Yes
07011200	186		03597500	222	Yes
07011500	187		03597550	223	
07017500	189		03604070	224	
07064300	190		03604090	226	
07064500	191		03604100	227	
			07028935	228	Yes

* See Appendix D, Table D.1

chapter illustrates the relationships that were developed and presents the methodology with which they were applied.

CHAPTER VII

DEVELOPMENT AND TESTING OF RELATIONSHIPS FOR PREDICTING MODEL PARAMETERS AS A FUNCTION OF BASIN CHARACTERISTICS

Introduction

The purpose of this study is the development of relationships to predict the Model parameters as a function of basin characteristics. Four of the ten parameters, DRN, EVC, RR and TP/TC, have been considered to not require a predicting relationship. This chapter presents the results of the efforts to develop relationships for the remaining six parameters, PSP, KSAT, RGF, BMSM, KSW, and TC. The thirty physical basin characteristics presented in Chapter V or their combinations are used as the independent variables. The purpose of this chapter is to present the development, application and testing of the resulting relationships.

The first section discusses the development of the relationships and presents the final equations. The second section discusses the procedure developed to apply these relationships at a site. The third section is concerned with the verification process used to judge the applicability of the methodology developed. A summary is included.

Development of Relationships

The relationships developed are based on the application of multiple regression techniques. The relationships were considered to be expressed in the form of an equation defined as

$$y = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n \qquad \text{(VII.1)}$$

where y is the Model parameter, a is a regression constant, and b_1, b_2, ...b_n are the regression coefficients for the basin characteristics or their combination represented by x_1, x_2, ...x_n. This equation was considered not only for all variables as recorded but also for the logarithmic transform of the variables. The use of the logarithmic transform assured prediction equations which could not yield negative values and which often produce better correlations in hydrology. The independent variables were considered with respect to two restrictions. First, if two variables were highly intercorrelated then only the one with the highest partial correlation with the dependent variable was allowed. Second, the combination of basin characteristics to form an independent variable was not allowed unless there was a physical basis in terms of hydrology, physiography, soils or climate. The specific independent variables were selected by a two-step procedure. First, independent variables were identified using stepwise inclusion as performed by a standardized multiple regression procedure.[1/] Second, pairs of independent variables which were highly intercorrelated were inspected so that only the variable which exhibited the higher partial correlation with the dependent variable was retained in the relationship.

[1/] Sowers et al., 1971.

The relationships developed were dependent on the data base of parameter values and basin characteristics available. As indicated in Chapter VI, the 124 calibrations on Table 21 were used as the data base for applying these techniques. In general, this sample was considered in four ways. First, the total sample of 124 was used to develop a set of relationships. Second, the sample of 36 selected using a stricter criteria and contained in the total sample was used to develop a set. Third, the total sample was divided into two regions, each of whose physiographic and climatic features were considered similar and data from each region was used in developing a set of equations. Finally, the total sample was considered in terms of individual states, provided a sufficient number of sites were available for a particular state. Thus, a site could have up to four sets of predicting equations for the parameters of interest. The four types of samples meant eight sets of equations for each dependent variable. These eight sets are identified as the total 124 (LARGE), the smaller set of 36 (SMALL), two regions one defined by Alabama, Georgia and Mississippi (SOUTH), and the other defined by Illinois and Missouri (NORTH), and the four states of Georgia (GEORGIA), Illinois (ILLINOIS), Mississippi (MISS) and Tennessee (TENN). The total number of calibrations within these samples are 124 for LARGE, 36 for SMALL, 68 for SOUTH, 32 for NORTH, 39 for GEORGIA, 23 for MISS, 24 for TENN, and 20 for ILLINOIS.

The final relationship for a dependent variable was established by requiring the same independent variables to be present for each of the eight sets of equations. The relationships were developed using three steps. First, stepwise multiple regression techniques were used to select which independent variable should be included for the relationship based on the data from one of the eight sets of sites. This step was repeated for each of the eight sets. Second, an independent variable was selected if it was found to be present in any of these eight sets. Third, pairs of independent variables were inspected for high intercorrelation so that only the variable exhibiting the higher correlation with the dependent variable would be retained. The actual equations for each of the eight sets were then determined for each dependent variable as a function of these selected independent variables.

The six Model parameters were used to define 10 dependent variables for which equations were developed. Seven of these dependent variables were concerned with the runoff producing parameters. Four of these seven are the parameters themselves, PSP, KSAT, RGF and BMSM. The other three of seven are concerned with the infiltration process shown by equations (II.5) and (II.6). The first of these, FRWET, is defined as the product of PSP and KSAT. The second, FRDRY, is the product of PSP, KSAT and RGF. These forms were previously introduced in Chapter IV. The third, FRVART, is formed by substituting values of 2.0 for SMS and 0.85 for BMS/BMSM into the equation formed by substituting equation (II.6) into equation (II.5) which is expressed as

$$FR = KSAT \left[1 + \frac{PSP}{SMS} \left(RGF - (RGF - 1) \frac{BMS}{BMSM}\right)\right] \tag{VII.2}$$

Then FRVART is expressed as

$$\text{FRVART} = \text{KSAT}\ [1 + \frac{\text{PSP}}{\text{SMS}}\ (.15\ \text{RGF} + .85)] \qquad (\text{VII}.3)^{2/}$$

Three of the ten dependent variables were concerned with the routing parameters, KSW and TC. Two of these are the parameters themselves while the other is defined as the basin lag time, LAG, which can be expressed as

$$\text{LAG} = \text{KSW} + 0.5\ \text{TC} \qquad (\text{VII}.4)$$

where KSW and TC are in hours.

Preliminary efforts to develop the relationships for these 10 dependent variables along the format expressed in equation (VII.1) showed better correlation with the logarithmic transforms for all dependent variables except RGF, and the failure of attempts to use simple linear regression equations involving only one independent variable as given by the form y = a + bx. These initial efforts also showed poor correlation using the measures of soil types and soil composition in terms of percentages of the total drainage basin as shown in Tables D.3 and D.4 of Appendix D. The number of independent

[2/] The selection of the values for SMS and BMS/BMSM is attributed to studies performed by R. W. Lichty in which the values were estimated by viewing the sensitivity, due to changes in SMS and BMS/BMSM, of the standard error of estimate for a regression model relating FRVART to flood peak (Lichty and Liscum, 1977).

variables retained in these equations varies from 6 to 9 which allows the preservation of the degrees of freedom from a maximum of 118 to a minimum of 11 for the eight sample sets used. The minimum is comparable to the degrees of freedom preserved in similar studies with the Kentucky Watershed Model.[3/] The resulting equations are presented by considering the runoff producing dependent variables first.

The runoff producing dependent variables are shown in Tables 22 through 28 to be functions of main channel slope, S, relief ratio, RRAT, mean overland flow slope, OVS, drainage density, DD, average available water capacity, AVE AWC, average permability of the surface layer, AHOR PERM, the infiltration value based on SCS hydrologic soils groupings, HSG INFIL, a measure of unsaturated hydraulic conductivity, MEAS KUN, a measure of effective capillary potential at field capacity, MEAS PS, a measure of the ratio of effective capillary potential at wilting point defined at a moisture tension of 3 bars, MEAS RGF3B, mean annual precipitation, MN PRECIP, the 2-year, 24-hour maximum precipitation, I24,2 and some combinations of characteristics. The combinations of basin characteristics used are (1) the value for equation (VII.3) if MEAS KUN, MEAS RGF3B and MEAS PS are substituted, FR UN3B, (2) the product of MEAS PS and MEAS RGF3B, (3) the product of AHOR PERM and depth to bedrock, DBR, and (4) the ratio of mean annual rainfall, MN PRECIP, to average available water capacity, AVE AWC. The predominance of soils characteristics is to be expected as these are the only

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[3/] For the relationships developed, Ross (1970) preserved 16 degrees of freedom, Ambaruch and Simmons (1973) 4 to 9, and Magette et al. (1976), 15.

means to view a numerical index to the infiltration process. The descriptive characteristics present are reasonable in that they can be viewed as an indicator of how long moisture would be in contact with the soils. The climate characteristics, MN PRECIP and I24,2, offer some index to potential moisture available for infiltration. With one exception the combinations used appear to be reasonable in that two, FR UN3B and MEAS PS * MEAS RGF3B, are formulated based on relationships used in the Model, and another, MN PRECIP/AVE AWC, is considered as a gross index for moisture allocation. Only the combination, AHOR PERM * DBR, does not appear to have some physical basis. The equations for the appropriate independent variables are stated in terms of the identifiers used above.

(1) PSP -- Table 22 shows that the logarithm to the base 10, LOG_{10}, of PSP has been expressed as a function of the logarithms to the base 10 of the 7 independent variables, OVS, S, DD, HSG INFIL, AHOR PERM, MEAS RGF3B, and FR UN3B. The multiple correlation coefficient, MCC, is shown to range from 0.477 to 0.883 for the eight sets while the standard error of estimate, SEE, ranges from 0.148 to 0.242. These variables do have an explainable influence on infiltration as indicated above. The absence of MEAS PS, due to its very low partial correlation with PSP (less than 0.1), causes some concern. However, noting the interaction present between PSP and KSAT in Chapter V, it was indicated that the individual calibrated values of these two parameters may be in question. For this reason, application of this equation set must consider the influence which these two parameters have on each other. Computation

of the actual value for PSP, in inches, can be indicated by considering the form of the equation for a sample. The example chosen is the sample designated as LARGE, and the computation is expressed as

$$\begin{aligned}\mathrm{LOG}_{10}\ (\mathrm{PSP}) = {} & 0.483 + 0.130 \times \mathrm{LOG}_{10}\ (\mathrm{OVS}) + 0.205 \times \mathrm{LOG}_{10}\ (\mathrm{S}) \\ & + 0.438 \times \mathrm{LOG}_{10}\ (\mathrm{HSG\ INFIL}) - 0.195 \times \mathrm{LOG}_{10}\ (\mathrm{AHOR\ PERM}) \\ & - 0.259 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ RGF3B}) - 0.103 \times \mathrm{LOG}_{10}\ (\mathrm{FR\ UN3B}) \\ & - 0.147 \times \mathrm{LOG}_{10}\ (\mathrm{DD}) \end{aligned} \tag{VII.5}$$

and $$\mathrm{PSP} = 10^{\mathrm{LOG}_{10}\ (\mathrm{PSP})} \tag{VII.6}$$

(2) KSAT -- Table 23 shows that the logarithm of KSAT has been expressed as a function of the logarithms of the 6 independent variables, OVS, HSG INFIL, MEAS KUN, AHOR PERM, I24,2 and MEAS PS x MEAS RGF3B. The multiple correlation coefficient for the eight sets, MCC, is shown to range from 0.562 to 0.807 for the eight sets while the standard errors of estimate, SEE, ranges from 0.152 to 0.240. As with PSP, the application of this equation set must be made with considerations given to the possible influences between these two parameters. Computation of the actual value of KSAT, in inches per hour, is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned}\mathrm{LOG}_{10}\ (\mathrm{KSAT}) = {} & -0.699 + 0.071 \times \mathrm{LOG}_{10}\ (\mathrm{OVS}) + 0.461 \times \mathrm{LOG}_{10}\ (\mathrm{HSG\ INFIL}) \\ & + 0.055 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ KUN}) + 0.103 \times \mathrm{LOG}_{10}\ (\mathrm{AHOR\ PERM}) \\ & - 2.098 \times \mathrm{LOG}_{10}\ (\mathrm{I24,2}) \\ & + 0.395 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ PS} \times \mathrm{MEAS\ RGF3B}) \end{aligned} \tag{VII.7}$$

and $$\mathrm{KSAT} = 10^{\mathrm{LOG}_{10}\ (\mathrm{KSAT})} \tag{VII.8}$$

Table 22. The Relationship Constant and Coefficients for Dependent Variable PSP

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	OVS	S	HSG INFIL	AHOR PERM	MEAS RGF3B	FR UN3B	DD
LARGE	0.546	0.239	29.8	0.483	0.130	0.205	0.438	-0.195	-0.259	-0.103	-0.147
SMALL	0.640	0.198	41.0	1.311	0.079	0.146	0.373	0.144	-0.840	-0.145	-0.178
SOUTH	0.477	0.242	22.7	-0.101	0.077	0.131	0.402	-0.366	0.273	-0.042	-0.023
NORTH	0.630	0.186	39.7	-0.356	-0.319	0.634	0.212	-0.070	0.576	-0.012	-0.367
GEORGIA	0.531	0.199	28.2	-0.172	0.197	-0.037	0.077	0.322	-0.345	0.142	0.337
MISS	0.814	0.190	66.2	-2.339	0.184	-0.224	0.194	0.196	1.781	-0.198	0.206
TENN	0.768	0.193	58.9	2.654	0.057	0.332	0.581	0.187	-1.608	0.474	-0.016
ILLINOIS	0.883	0.148	78.0	-4.449	-0.363	0.811	0.313	-0.458	3.992	0.777	-0.397

Table 23. The Relationship Constant and Coefficients for Dependent Variable KSAT

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	OVS	HSG INFIL	MEAS KUN	AHOR PERM	I24,2	MEAS PS* MEAS RGF3B
LARGE	0.646	0.209	41.8	-0.699	0.071	0.461	0.055	0.103	-2.098	0.395
SMALL	0.652	0.175	42.4	-0.857	-0.007	0.309	-0.061	0.333	-1.798	0.277
SOUTH	0.765	0.193	58.5	-2.696	0.242	0.351	0.015	0.326	-0.804	0.589
NORTH	0.562	0.202	31.5	0.354	-0.150	0.330	0.065	0.076	-1.485	-0.017
GEORGIA	0.628	0.180	39.4	-0.617	0.219	0.625	0.084	0.545	-1.228	-0.012
MISS	0.755	0.212	56.9	-6.380	0.410	-0.159	-0.034	0.188	1.760	1.021
TENN	0.597	0.240	35.6	-1.874	0.238	1.201	0.154	-0.114	-0.334	0.672
ILLINOIS	0.807	0.154	65.1	-14.900	-0.076	-0.688	0.933	1.344	0.405	6.509

(3) RGF -- Table 24 shows that the value of RGF has been expressed as a function of the 6 independent variables, OVS, S, HSG INFIL, AHOR PERM, MN PRECIP/AVE AWC, and MEAS PS x MEAS RGF3B. The multiple correlation coefficient for the eight sets ranges from 0.322 to 0.844, and the standard error of estimate ranges from 3.60 to 8.70. Computation of the actual dimensionless value of RGF is illustrated using the LARGE sample. This is expressed as:

$$\begin{aligned} RGF = {} & 9.322 - 0.002 \times OVS - 0.004 \times S \\ & + 35.260 \times HSG\ INFIL + 0.090 \times AHOR\ PERM \\ & + 0.095 \times (MN\ PRECIP/AVE\ AWC) \\ & - 0.005 \times (MEAS\ PS \times MEAS\ RGF3B) \end{aligned} \qquad (VII.9)$$

(4) BMSM -- Table 25 shows that the logarithm of BMSM has been expressed as a function of the logarithms of the 7 independent variables, AHOR PERM, MN PRECIP, AHOR PERM x DBR, FR UN3B, I24,2, DD and AVE AWC. The multiple correlation coefficient for the eight sets ranges between 0.358 and 0.777, and the standard error of estimate ranges between 0.175 to 0.267. Despite a fairly high partial correlation (greater than 0.7) with AHOR PERM, the product, AHOR PERM x DBR, was allowed to remain in this relationship as a means to having an intuitively appealing variable depth to bedrock (DBR) included. Computation of the actual value of BMSM, in inches is illustrated using the LARGE sample. This is expressed as:

Table 24. The Relationship Constant and Coefficients for Dependent Variable RGF

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	OVS	S	HSG INFIL	AHOR PERM	MN PRECIP ÷ AVE AWC	MEAS PS* MEAS RGF3B
LARGE	0.322	7.435	10.4	9.322	-0.002	-0.004	35.260	0.090	0.095	-0.005
SMALL	0.432	7.460	18.6	21.620	-0.010	-0.004	6.502	-0.524	0.197	-0.015
SOUTH	0.467	7.811	21.8	6.189	-0.005	-0.014	48.240	0.708	0.167	-0.013
NORTH	0.492	7.165	24.2	1.208	0.008	-0.049	1.267	-1.565	-0.828	0.103
GEORGIA	0.373	8.062	13.9	30.390	-0.009	-0.000	-13.380	-0.436	0.136	-0.025
MISS	0.844	3.600	71.3	-2.074	-0.001	-0.030	62.300	-2.325	0.625	0.014
TENN	0.682	4.890	46.4	0.955	-0.002	0.016	81.420	-0.633	-0.163	0.023
ILLINOIS	0.384	8.700	14.7	0.188	0.009	-0.050	30.750	-5.196	-0.981	0.115

Table 25. The Relationship Constant and Coefficients for Dependent Variable BMSM

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	AHOR PERM	MN PRECIP	AHOR PERM * DBR	FR UN3B	I24,2	DD	AVE AWC
LARGE	0.449	0.223	20.2	-0.583	0.390	0.480	-0.058	0.046	0.326	0.135	0.208
SMALL	0.532	0.241	28.3	-2.099	0.326	1.892	0.051	0.113	-1.864	0.278	0.214
SOUTH	0.358	0.215	12.8	0.836	-0.028	-0.224	0.142	0.102	-0.509	0.250	0.183
NORTH	0.577	0.236	33.3	4.719	0.968	-2.871	-0.415	-0.186	1.326	0.062	0.193
GEORGIA	0.602	0.175	36.3	-3.193	0.187	1.767	0.145	0.180	0.735	-0.001	0.136
MISS	0.437	0.267	19.1	-6.050	-0.613	4.648	0.412	-0.173	-3.570	0.407	-0.230
TENN	0.503	0.203	25.3	-1.802	0.205	1.778	0.119	-0.094	-1.884	-0.151	0.194
ILLINOIS	0.777	0.216	59.5	17.060	6.400	-4.028	-6.010	0.159	2.195	0.255	0.754

$$\begin{aligned}\mathrm{LOG}_{10}\ (\mathrm{BMSM}) = {} & -0.583 + 0.390 \times \mathrm{LOG}_{10}\ (\mathrm{AHOR\ PERM}) \\ & + 0.480 \times \mathrm{LOG}_{10}\ (\mathrm{MN\ PRECIP}) \\ & - 0.058 \times \mathrm{LOG}_{10}\ (\mathrm{AHOR\ PERM \times DBR}) \\ & + 0.046 \times \mathrm{LOG}_{10}\ (\mathrm{FR\ UN3B}) \\ & + 0.326 \times \mathrm{LOG}_{10}\ (\mathrm{I24,2}) \\ & + 0.135 \times \mathrm{LOG}_{10}\ (\mathrm{DD}) \\ & + 0.208 \times \mathrm{LOG}_{10}\ (\mathrm{AVE\ AWC}) \end{aligned} \qquad (\mathrm{VII.10})$$

and $$\mathrm{BMSM} = 10^{\mathrm{LOG}_{10}\ (\mathrm{BMSM})} \qquad (\mathrm{VII.11})$$

(5) FRWET -- Table 26 shows that the logarithm of FRWET, which is PSP x KSAT, has been expressed as a function of the 9 independent variables, OVS, RRAT, DD, HSG INFIL, MEAS KUN, AHOR PERM, MEAS PS, MEAS RGF3B, and I24,2. The multiple correlation coefficient for the eight sets ranges from 0.568 to 0.884 and standard error of estimate ranges from 0.270 to 0.386. This variate may be viewed as a means to determine the validity of the values produced by the equations for PSP and KSAT. Computation of the actual value for FRWET is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned}\mathrm{LOG}_{10}\ (\mathrm{FRWET}) = {} & -0.909 + 0.180 \times \mathrm{LOG}_{10}\ (\mathrm{OVS}) \\ & + 0.159 \times \mathrm{LOG}_{10}\ (\mathrm{RRAT}) + 0.001 \times \mathrm{LOG}_{10}\ (\mathrm{DD}) \\ & + 0.856 \times \mathrm{LOG}_{10}\ (\mathrm{HSG\ INFIL}) \\ & - 0.073 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ KUN}) \\ & - 0.153 \times \mathrm{LOG}_{10}\ (\mathrm{AHOR\ PERM}) \\ & + 0.666 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ PS}) + 0.276 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ RGF3B}) \\ & - 2.135 \times \mathrm{LOG}_{10}\ (\mathrm{I24,2}) \end{aligned} \qquad (\mathrm{VII.12})$$

$$\text{and} \quad FRWET = 10^{LOG_{10}\ (FRWET)} \tag{VII.13}$$

(6) FRDRY -- Table 27 shows that the logarithm of FRDRY, which is PSP x KSAT x RGF, has been expressed as a function of the logarithms of the same 9 variables used for FRWET. The multiple correlation coefficient for the eight sets range from 0.555 to 0.876, and the standard error of estimate ranges from 0.295 to 0.503. Similar to FRWET, this variate may be viewed as a means to determine the validity of the predicted values of PSP, KSAT and RGF. Computation of the actual value for FRDRY is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned} LOG_{10}\ (FRDRY) = {} & 0.231 + 0.144 \times LOG_{10}\ (OVS) + 0.193 \times LOG_{10}\ (RRAT) \\ & - 0.042 \times LOG_{10}\ (DD) + 1.215 \times LOG_{10}\ (HSG\ INFIL) \\ & - 0.146 \times LOG_{10}\ (MEAS\ KUN) \\ & - 0.186 \times LOG_{10}\ (AHOR\ PERM) \\ & + 0.713 \times LOG_{10}\ (MEAS\ PS) \\ & + 0.566 \times LOG_{10}\ (MEAS\ RGF3B) \\ & - 2.638 \times LOG_{10}\ (I24,2) \end{aligned} \tag{VII.14}$$

$$\text{and} \quad FRDRY = 10^{LOG_{10}\ (FRDRY)} \tag{VII.15}$$

(7) FRVART -- Table 28 shows that the logarithm of FRVART, which is defined in equation (VII.3), has been expressed as a function of the logarithms of the same 9 variables used for FRWET and FRDRY. The multiple correlation coefficient for the eight sets ranges from 0.593 to

Table 26. The Relationship Constant and Coefficients for Dependent Variable FRWET

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	OVS	RRAT	DD	HSG INFIL	MEAS KUN	AHOR PERM	MEAS PS	MEAS RGF3B	I24,2
LARGE	0.568	0.381	32.2	-0.909	0.180	0.159	0.001	0.856	-0.073	-0.153	0.666	0.276	-2.135
SMALL	0.683	0.286	46.7	2.841	-0.064	0.307	0.116	0.476	0.043	0.817	-0.902	-1.675	-1.412
SOUTH	0.671	0.324	45.0	-7.829	0.463	-0.020	0.243	0.342	-0.077	-0.070	1.781	1.688	2.133
NORTH	0.576	0.365	33.2	3.252	-0.629	0.899	-0.174	0.488	0.307	0.170	-1.744	-0.359	-1.585
GEORGIA	0.678	0.296	46.0	0.702	0.545	0.123	-0.138	0.674	0.099	1.240	0.520	-0.157	-6.096
MISS	0.817	0.386	66.8	-10.840	0.524	0.057	0.235	-0.212	-0.216	0.450	1.664	2.743	2.828
TENN	0.782	0.380	61.7	-2.560	0.204	0.692	0.899	1.808	0.391	-0.298	1.911	0.295	-0.988
ILLINOIS	0.884	0.270	78.1	-25.660	-1.029	1.816	-0.656	-0.324	2.357	0.815	10.810	13.620	1.211

Table 27. The Relationship Constant and Coefficients for Dependent Variable FRDRY

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	OVS	RRAT	DD	HSG INFIL	MEAS KUN	AHOR PERM	MEAS PS	MEAS RGF3B	I24,2
LARGE	0.587	0.449	34.5	0.231	0.144	0.193	-0.042	1.215	-0.146	-0.186	0.713	0.566	-2.638
SMALL	0.604	0.378	36.5	6.897	-0.314	0.434	0.103	0.708	0.218	0.881	-2.051	-2.281	-1.310
SOUTH	0.745	0.347	55.5	-8.120	0.600	0.030	0.075	0.619	-0.241	0.166	1.743	1.999	2.815
NORTH	0.568	0.503	32.3	0.806	-0.402	0.383	-0.072	0.711	0.322	-0.111	0.720	2.054	-4.681
GEORGIA	0.555	0.295	30.8	0.775	0.140	0.241	-0.062	0.871	-0.189	0.648	0.608	0.082	-3.852
MISS	0.876	0.416	76.7	-9.468	1.037	-0.428	0.093	0.638	-0.362	0.050	-0.662	3.573	4.213
TENN	0.866	0.357	75.0	1.187	0.176	0.946	1.411	2.373	0.307	-0.294	0.017	-0.236	-1.884
ILLINOIS	0.798	0.453	63.7	-69.700	-0.792	1.202	-1.245	-0.550	2.522	0.251	37.840	31.010	-5.956

Table 28. The Relationship Constant and Coefficients for Dependent Variable FRVART

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	OVS	RRAT	DD	HSG INFIL	MEAS KUN	AHOR PERM	MEAS PS	MEAS RGF3B	I24,2
LARGE	0.600	0.368	35.9	-0.146	0.119	0.169	-0.003	0.988	-0.088	-0.116	0.596	0.406	-2.373
SMALL	0.675	0.274	45.5	4.078	-0.219	0.366	0.097	0.542	0.063	0.808	-1.249	-1.640	-1.369
SOUTH	0.750	0.282	56.2	-7.081	0.469	0.017	0.140	0.482	-0.129	0.113	1.544	1.680	2.071
NORTH	0.593	0.376	35.1	1.800	-0.443	0.506	-0.080	0.572	0.305	-0.008	-0.501	0.932	-2.985
GEORGIA	0.633	0.245	40.1	0.205	0.291	0.177	-0.112	0.744	-0.053	0.823	0.492	0.033	-3.776
MISS	0.854	0.358	72.9	-8.640	0.595	-0.118	0.178	0.337	-0.227	0.184	0.200	3.119	2.583
TENN	0.848	0.340	71.9	-0.686	0.174	0.824	1.179	2.115	0.296	-0.316	0.838	0.067	-1.526
ILLINOIS	0.838	0.308	70.3	-40.610	-0.708	1.215	-0.835	-0.473	2.195	0.668	20.070	19.440	-1.681

0.854, and the standard errors of estimate ranges from 0.245 to 0.376. As with FRDRY, this variate may be viewed as a means to determine the validity for PSP, KSAT and RGF. Computation of the actual value of FRVART is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned}\mathrm{LOG}_{10}\ (\mathrm{FRVART}) = &- 0.146 + 0.119 \times \mathrm{LOG}_{10}\ (\mathrm{OVS}) \\ &+ 0.169 \times \mathrm{LOG}_{10}\ (\mathrm{RRAT}) - 0.003 \times \mathrm{LOG}_{10}\ (\mathrm{DD}) \\ &+ 0.988 \times \mathrm{LOG}_{10}\ (\mathrm{HSG\ INFIL}) - 0.088 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ KUN}) \\ &- 0.116 \times \mathrm{LOG}_{10}\ (\mathrm{AHOR\ PERM}) + 0.596 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ PS}) \\ &+ 0.406 \times \mathrm{LOG}_{10}\ (\mathrm{MEAS\ RGF3B}) \\ &- 2.373 \times \mathrm{LOG}_{10}\ (\mathrm{I24,2})\end{aligned} \qquad (\mathrm{VII.16})$$

and $$\mathrm{FRVART} = 10^{\mathrm{LOG}_{10}\ (\mathrm{FRVART})} \qquad (\mathrm{VII.17})$$

The routing dependent variables are shown in Tables 29 through 31 to be functions of drainage density, DD, a basin shape factor, SHAPE, percent forested area, F, and combinations of the various measurements of stream length and slope. These combinations of basin characteristics used are the ratio of main channel length to the square root of main channel slope, $L/\sqrt{S}$, the ratio of mean overland flow length to the square root of the mean overland flow slope, $OVL/\sqrt{OVS}$, and the ratio of the total length of all channels to the main channel length, LCHAN/L. As expected, the descriptive characteristics are the only type which enter into these equations. Drainage density, DD, and the ratio of total length of channels to the main channel length, LCHAN/L, provide an index to the drainage efficiency of the basin. The basin shape factor, SHAPE, is considered a gross representation of overland flow length ($\rho < .2$). Percent forested area is considered to have a restricting effect on surface runoff. The terms, $L/\sqrt{S}$ and $OVL/\sqrt{OVS}$, are considered to be indicative of basin lag time. This has been shown for $L/\sqrt{S}$ by Wibben (1976b) and is assumed to be the case for $OVL/\sqrt{OVS}$. The equations for the appropriate dependent variables are presented below. Reference to these independent variables is stated in terms of the identifiers used above.

(1) KSW -- Table 29 shows that the logarithm of KSW has been expressed as a function of the logarithms of the 6 independent variables, DD, SHAPE, F, $L/\sqrt{S}$, $OVL/\sqrt{OVS}$, and LCHAN/L. The multiple correlation coefficient for the eight sets ranges from 0.647 to 0.939, and the standard errors of estimate ranges from 0.188 to 0.320. Computation of the actual value of KSW, in hours, is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned} LOG_{10}\ (KSW) = {} & 1.459 + 0.050 \times LOG_{10}\ (DD) + 0.343 \times LOG_{10}\ (SHAPE) \\ & + 0.372 \times LOG_{10}\ (F) + 0.601 \times LOG_{10}\ (L/\sqrt{S}) \\ & + 0.566 \times LOG_{10}\ (OVL/\sqrt{OVS}) - 0.074 \times LOG_{10}\ (LCHAN/L) \qquad (VII.18) \end{aligned}$$

and $$KSW = 10^{LOG_{10}\ (KSW)} \qquad (VII.19)$$

(2) TC -- Table 30 shows that the logarithm of TC has been expressed as a function of the logarithms of the same 6 variables used for KSW. The multiple correlation coefficient for the eight sets ranges from 0.556 to 0.916 and the standard error of estimate ranges from

Table 29. The Relationship Constant and Coefficients for Dependent Variable KSW

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	DD	SHAPE	F	L ÷ $\sqrt{S}$	OVL ÷ $\sqrt{OVS}$	LCHAN ÷ L
LARGE	0.774	0.320	60.0	1.459	0.050	0.343	0.372	0.601	0.566	-0.074
SMALL	0.815	0.291	66.5	2.069	-0.010	0.326	0.291	0.450	0.830	-0.191
SOUTH	0.860	0.232	74.0	1.387	0.627	0.876	0.392	0.976	0.459	-0.215
NORTH	0.831	0.281	69.1	0.938	0.524	1.367	-0.012	1.493	-0.325	-1.105
GEORGIA	0.882	0.188	77.7	0.847	-1.345	-0.322	0.494	0.019	0.395	0.839
MISS	0.647	0.279	41.9	1.738	0.992	1.047	0.489	0.951	0.740	-0.391
TENN	0.765	0.239	58.5	1.428	-2.968	-2.259	0.728	-1.516	1.400	1.966
ILLINOIS	0.939	0.223	88.1	0.658	1.649	1.949	-0.064	2.353	-0.573	-1.713

Table 30. The Relationship Constant and Coefficients for Dependent Variable TC

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	DD	SHAPE	F	L ÷ $\sqrt{S}$	OVL ÷ $\sqrt{OVS}$	LCHAN ÷ L
LARGE	0.765	0.250	58.5	0.901	-0.027	0.093	0.237	0.427	0.326	0.140
SMALL	0.867	0.221	75.2	1.094	-0.680	-0.292	0.091	0.083	0.455	0.801
SOUTH	0.803	0.239	64.5	1.075	-0.277	0.081	0.092	0.519	0.203	0.227
NORTH	0.591	0.279	34.9	0.432	0.306	0.150	0.069	0.520	0.113	-0.054
GEORGIA	0.916	0.147	84.0	1.133	-0.967	-0.302	-0.012	0.278	0.105	0.429
MISS	0.556	0.359	31.0	1.098	1.252	1.418	0.108	1.492	-0.098	-1.026
TENN	0.825	0.163	68.0	1.800	-2.025	-1.264	0.426	-0.841	1.128	1.600
ILLINOIS	0.819	0.247	67.1	-0.337	-0.175	-0.386	0.142	0.541	-0.239	0.456

0.147 to 0.359. Computation of the actual value of TC, in hours, is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned} LOG_{10}\ (TC) = 0.901 &- 0.027 \times LOG_{10}\ (DD) + 0.093 \times LOG_{10}\ (SHAPE) \\ &+ 0.237 \times LOG_{10}\ (F) + 0.427 \times LOG_{10}\ (L/\sqrt{S}\ ) \\ &+ 0.326 \times LOG_{10}\ (OVL/\sqrt{OVS}) \\ &+ 0.140 \times LOG_{10}\ (LCHAN/L) \end{aligned} \tag{VII.20}$$

$$\text{and}\quad TC = 10^{LOG_{10}\ (TC)} \tag{VII.21}$$

(3) LAG -- Table 31 shows that the logarithm of LAG has been expressed as a function of the logarithms of the same 6 variables used for KSW and TC. The multiple correlation coefficient for the eight sets ranges from 0.660 to 0.918, and the standard error of estimate ranges from 0.154 to 0.248. Computation of the actual value of LAG, in hours, is illustrated using the LARGE sample. This is expressed as

$$\begin{aligned} LOG_{10}\ (LAG) = 1.402 &+ 0.003 \times LOG_{10}\ (DD) + 0.190 \times LOG_{10}\ (SHAPE) \\ &+ 0.312 \times LOG_{10}\ (F) + 0.491 \times LOG_{10}\ (L/\sqrt{S}\ ) \\ &+ 0.474 \times LOG_{10}\ (OVL/\sqrt{OVS}) \\ &+ 0.049 \times LOG_{10}\ (LCHAN/L) \end{aligned} \tag{VII.22}$$

$$\text{and}\quad LAG = 10^{LOG_{10}\ (LAG)} \tag{VII.23}$$

This section has presented the final form of the equations for the dependent variables as determined for eight samples. Comparison between the runoff producing dependent variables and those from the

Table 31. The Relationship Constant and Coefficients for Dependent Variable LAG

Sample ID	MCC	SEE	% EXP VAR	CONSTANT	DD	SHAPE	F	L ÷ $\sqrt{S}$	OVL ÷ $\sqrt{OVS}$	LCHAN ÷ L
LARGE	0.811	0.248	65.8	1.402	0.003	0.190	0.312	0.491	0.474	0.049
SMALL	0.875	0.208	76.6	1.839	-0.005	0.266	0.209	0.459	0.626	0.018
SOUTH	0.882	0.191	77.8	1.390	0.019	0.344	0.266	0.630	0.378	0.174
NORTH	0.823	0.214	67.7	0.932	0.632	1.054	0.037	1.215	-0.203	-0.899
GEORGIA	0.914	0.154	83.6	1.104	-1.187	-0.295	0.349	0.125	0.302	0.682
MISS	0.660	0.248	43.6	1.686	1.101	1.171	0.348	1.113	0.444	-0.613
TENN	0.792	0.191	62.7	1.723	-2.675	-1.944	0.579	-1.304	1.292	1.942
ILLINOIS	0.918	0.196	84.3	0.440	1.079	1.255	0.012	1.739	-0.538	-1.053

routing portion of the Model show that the routing dependent variables exhibited a better fit for these equations. This is attributed to the fact that not only is the routing component more easily modeled and calibrated, but also the measurements of soils characteristics on a watershed are not accurate, and the process relating soils characteristics and runoff production is not well defined.

Application of Relationships

The determination of relationships for 10 dependent variables to predict values for 6 Model parameters makes it apparent that some procedure must be employed to determine the actual values for the six parameters. This section presents the procedure that was developed. The procedure consists of two parts. The first determines the parameter values required for the runoff producing portion of the Model, and the second determines the routing parameters.

As stated previously, the four runoff producing parameters, PSP, KSAT, RGF and BMSM, have been represented by seven dependent variables, PSP, KSAT, RGF, BMSM, FRWET, FRDRY, and FRVART. Comparisons between the equations developed for the seven dependent variables showed that none of them could be considered appreciably better than another. The dependent variables representing the infiltration process should exhibit some consistency. With the exception of BMSM, the three variates representing the infiltration process contained at least two of the three remaining parameters. Thus, it could be possible to insure that the values predicted for PSP, KSAT and RGF are somewhat compatible with the variates, FRWET, FRDRY, and FRVART. Preliminary tests showed that the use of FRWET, a function of PSP and KSAT, was more appropriate than FRDRY and FRVART, both of whom are functions of PSP, KSAT and RGF. This is attributed to the fact that both PSP and KSAT have been shown not only to be the most sensitive runoff producing parameters, but also the determination of their values by calibration has not been shown to yield unquestionable correct values, due to interaction. RGF, on the other hand, is not as sensitive nor did it exhibit as definable interaction.

The procedure adopted is described as follows:

(1) The values for PSP, KSAT and FRWET are determined from their appropriate equations.

(2) If KSAT is less than 0.010 then the actual KSAT value is determined from the relation, KSAT = FRWET/PSP.

(3) If KSAT is greater than or equal to 0.010 then the actual PSP value is determined from the above relation with FRWET.

(4) Both KSAT and PSP are checked to see whether or not they have been given values greater than the upper bounds of 0.75 for KSAT and 50.0 for PSP. If so, they are set at these upper bounds.

(5) RGF is determined from its appropriate equation and not allowed to violate the bounds of 1.0 and 50.0. If it does violate these bounds it is arbitrarily set at a value equal to 15.0 which approximates its calibrated mean.

(6) BMSM is determined from its appropriate equation and not allowed to violate the bounds of 0.5 and 25.0. If it does violate these bounds it is arbitrarily set at a value equal to 5.0 which approximates its calibrated mean.

This procedure insures that PSP, KSAT and FRWET are compatible. If the upper bounds of PSP and KSAT are exceeded, although they were not for this study, these values are considered as a warning that other values should be selected. Table 32 shows a comparison between the values computed for the mean, maximum and minimum of the dependent variables determined from the calibrated parameters and the means, maximums and minimums determined from all 8 sets of predicting equations. These equations do confine the values of PSP and KSAT below the upper bound. The range of values produced for RGF and BMSM are also considered acceptable.

The routing parameters, KSW and TC, are described by three dependent variates, KSW, TC and LAG. Comparisons between the equations for these dependent variables showed little difference in error measures for each of the eight sets. The procedure adopted to predict the actual values was simply the application of the separate equations for KSW and TC. The value of TC was then checked to insure that its value was not less than that produced from the equation for LAG. This was done because examination of values for TC computed both ways show that the value from the LAG equation tended to be less and, in fact, could go negative. Thus, it was assumed that TC from LAG was a lower limit, and that the value of TC should not be less than this value.

The procedure adopted is described as follows:

(1) KSW is determined from its equation.

(2) TC is determined from its equation.

(3) TC_{LAG} is determined from the equation for LAG. This is

Table 32. Comparison between Values Computed for the Mean, Maximum and Minimum of the Dependent Variables Determined from the Final Calibrations and Determined from all Eight Sets of Predicting Equations

Dependent Variable	Measure	Value for Complete Calibrated Set	Value from Considering All Eight Predicting Equation Sets
PSP			
	MEAN*	2.19	1.86
	MAX	9.97	7.92
	MIN	.30	.38
KSAT			
	MEAN*	.063	.056
	MAX	.250	.392
	MIN	.010	.004
RGF			
	MEAN	14.6	14.6
	MAX	42.9	29.1
	MIN	2.0	1.0
BMSM			
	MEAN*	4.75	3.92
	MAX	14.70	8.21
	MIN	1.04	1.12
FRWET			
	MEAN*	.138	.105
	MAX	1.62	1.32
	MIN	.0049	.0017
FRDRY			
	MEAN*	1.72	3.24
	MAX	29.91	99.30
	MIN	.010	.011
FRVART			
	MEAN*	.47	.39
	MAX	5.35	9.94
	MIN	.018	.008

Table 32. continued

Dependent Variable	Measure	Value for Complete Calibrated Set	Value from Considering All Eight Predicting Equation Sets
KSW			
	MEAN*	1.76	1.55
	MAX	21.50	28.10
	MIN	.090	.056
TC			
	MEAN*	1.96	1.75
	MAX	15.00	11.20
	MIN	.17	.21
LAG			
	MEAN*	2.89	2.70
	MAX	26.12	28.90
	MIN	.30	.19

Note: * Indicates value computed as the antilog of the mean of logs.

expressed as:

$$TC_{LAG} = 2.0 \times (LAG - KSW) \qquad (VII.24)$$

where TC_{LAG}, LAG and KSW are in hours.

(4) If TC is less than TC_{LAG}, then TC is set equal to TC_{LAG}, unless TC_{LAG} is negative in which case TC is set equal to KSW.

This procedure assumes that KSW is as well defined as needed by its relationship and insures that TC is not given an unrealistically low value. The results for comparing the means, maximums and minimums of KSW and TC in Table 32 show that the values given are within the limits from the calibrated data.

This combined procedure allows the determination of actual values for PSP, KSAT, RGF, BMSM, KSW and TC. The resulting predicted parameter values are presented in Table D.10 of Appendix D for each applicable set of equations. As a practical result the dependent variables are limited to PSP, KSAT, RGF, BMSM, FRWET, KSW, TC, and LAG. Table 32 indicates that the values produced are within acceptable ranges of the calibrated parameters.

Verification of Relationships

It is necessary to verify these relationships prior to their use at ungaged sites in order to gain insight into their validity for such an application. The use of the Model at an ungaged site requires the parameter values predicted for the site from these relationships to approximate those values which would have been determined had the parameters been calibrated with sufficient site data. Secondly, the use of the predicted parameter values at the ungaged site must yield comparable results to those which would have resulted if calibrated parameter values had been available when the Model is applied to create flood peak data for flood frequency determinations at the ungaged site. Thus, verification of these developed relationships is approached, first, by comparing the amount of agreement between predicted and calibrated parameter values and the manner in which the predicted parameters and calibrated parameters reproduce observed peaks and volumes, and second, by comparing the results for predicted and calibrated parameters in the computation of n-year recurrence interval floods by a multiple regression model including some of the Model parameters.

The first approach to verification is accomplished by viewing how the predicted parameters agree with the calibrated parameters, and by comparing the results of Model simulations based on the predicted parameters to simulations based on the calibrated parameters. The predicted Model parameters may be compared to the calibrated parameters on the basis of the correlation coefficient, $R_{x,y}$. $R_{x,y}$ was computed for the relation between the calibrated and predicted parameters for the 8 dependent variables, PSP, KSAT, RGF, BMSM, FRWET, KSW, TC and LAG. The correlation coefficient was computed for the logical pairs for each set of equations. For example, the calibrated values for PSP were compared to predicted values of both PSP and FRWET over the entire sample of 237 sites for PSP and FRWET determined from the equations for the LARGE and SMALL samples, but only the calibrated values for PSP in Georgia were compared to values of PSP and FRWET predicted from the

GEORGIA equation. Table 33 presents the resulting correlation coefficient values, $R_{x,y}$. The column headed, LIMITING $R_{x,y}$, gives the value which $R_{x,y}$ may not be equal to or less than if the null hypothesis that $\rho_{x,y}$ equals 0.0 is to be rejected by a Student t test at the 90 percent confidence level. Examination of this table show that only four failures have occurred in terms of accepting the null hypothesis. All of these occur for runoff producing associated variables, and three happen in the attempt to keep PSP, KSAT and FRWET compatible. In general, the dependent variables associated with the routing component exhibit a higher degree of agreement as shown by the higher correlation coefficients of Table 33. The equation sets do appear to predict parameter values which have some agreement with the calibrated values as indicated by the statistical test rejecting the null hypothesis of no correlation.

The Model results are also compared on the basis of the error measures, VOLUME, ROUTING, and TOTAL, as defined in Chapter II and expressed as percent. Of the 237 calibrations available, 20 sites were selected at random for this comparison. This included 11 sites which had not been part of the final 124 chosen, and 9 that were. Table 34 shows the results obtained for each of these test sites for the applicable equations including possibly one of the regional samples, SOUTH and NORTH, and/or a state sample, GEORGIA, ILLINOIS, MISS and TENN. A predicted parameter set is considered acceptable if the resulting error produced is within 10 percent of the value produced by the

Table 33. Coorelation Coefficients between Eight Calibrated and Predicted Variables Used to Apply the Developed Relationships

Equation Set ID	Sample Size	Limiting $R_{x,y}$	Calibrated	PSP		KSAT		RGF	BMSM	FRWET			KSW	TC		LAG	
			Predicted	PSP	FRWET	KSAT	FRWET	RGF	BMSM	PSP	KSAT	FRWET	KSW	TC	TC.LAG	TC	TC,LAG
LARGE	237	0.107		0.467	0.337	0.614	0.509	0.200	0.324	0.358	0.423	0.511	0.742	0.737	0.719	0.772	0.744
SMALL	237	0.107		0.203	0.145	0.576	0.387	0.074	0.213	0.134	0.336	0.318	0.676	0.706	0.656	0.741	0.685
SOUTH	137	0.140		0.540	0.402	0.700	0.606	0.281	0,191	0.343	0.516	0.648	0.778	0.739	0.686	0.802	0.723
NORTH	61	0.212		0.325	0.178	0.428	0.451	0.226	0.384	0.343	0.121	0.358	0.842	0.632	0.571	0.748	0.691
GEORGIA	62	0.211		0.458	0.382	0.483	0.477	0.287	0.386	0.513	0.421	0.543	0.838	0.893	0.898	0.883	0.884
ILLINOIS	34	0.286		0.435	0.316	0.288	0.302	0.343	0.630	0.374	0.047	0.356	0.923	0.638	0.400	0.628	0.351
MISS	43	0.254		0.557	0.546	0.595	0.605	0.506	0.310	0.611	0.588	0.615	0.393	0.422	0.429	0.451	0.450
TENN	39	0.266		0.596	0.685	0.592	0.684	0.440	0.448	0.629	0.622	0.729	0.444	0.632	0.584	0.539	0.511

Table 34. List of Error Measures, in Percent, for Comparison of Predicted and Calibrated Parameter Values

Station No.	Member Sample LARGE	VOLUME ERROR Parameter Values from FINAL CALIB.	VOLUME ERROR Equations for LARGE	VOLUME ERROR Equations for SMALL	VOLUME ERROR Equations for REGION	VOLUME ERROR Equations for STATE	ROUTING ERROR Parameter Values from FINAL CALIB.	ROUTING ERROR Equations for LARGE	ROUTING ERROR Equations for SMALL	ROUTING ERROR Equations for REGION	ROUTING ERROR Equations for STATE	TOTAL ERROR Parameter Values from FINAL CALIB.	TOTAL ERROR Equations for LARGE	TOTAL ERROR Equations for SMALL	TOTAL ERROR Equations for REGION	TOTAL ERROR Equations for STATE
ALABAMA																
02363055	No	71.1	116.4	156.8	82.5	-	24.0	37.7	72.8	26.0	-	65.0	149.5	300.7	85.3	-
02451750	Yes	78.0	108.3	125.9	103.2	-	49.5	45.1	31.9	63.0	-	62.6	78.1	114.5	68.6	-
GEORGIA																
02189030	No	37.0	65.1	191.9	37.8	83.1	25.3	34.3	65.8	29.9	57.9	25.9	54.2	119.9	37.7	56.5
02191280	Yes	35.8	48.7	41.9	44.4	44.8	37.3	36.8	35.4	42.2	36.5	27.6	50.2	39.5	50.7	39.5
02202950	Yes	45.4	56.0	63.8	50.5	44.2	23.4	36.1	38.3	36.4	40.9	38.0	37.0	34.5	36.5	45.1
02217660	No	68.3	49.3	45.1	55.5	43.7	36.0	85.3	77.0	96.5	92.6	61.4	84.9	76.6	59.5	78.0
ILLINOIS																
05418800	Yes	78.5	93.7	82.1	74.0	76.4	61.4	64.6	67.5	78.8	65.6	42.3	51.8	60.0	74.1	61.1
05437600	No	106.2	99.9	99.7	102.4	117.8	17.3	36.3	35.9	20.7	13.0	101.1	114.4	117.5	106.6	104.8
05551800	No	65.3	142.5	121.4	119.5	76.0	27.3	19.6	19.6	32.4	31.4	53.4	133.5	111.3	95.0	69.8
MISSISSIPPI																
02485780	Yes	70.3	79.1	69.9	90.3	91.4	43.4	85.8	76.7	87.7	84.4	46.2	53.7	54.7	49.4	47.6
02487670	No	62.8	142.0	180.8	123.6	113.0	27.5	22.6	30.5	29.5	27.9	62.1	134.0	204.1	99.3	98.1
07282300	Yes	89.4	95.7	89.6	117.0	118.6	48.3	83.2	77.3	69.8	74.1	50.0	56.3	62.1	55.7	55.7
07290525	No	69.1	70.3	78.1	70.3	71.8	27.5	28.0	46.3	33.1	29.0	52.1	53.5	67.2	54.5	53.0
MISSOURI																
05497700	No	158.0	220.3	180.8	157.5	-	37.8	75.0	83.1	52.6	-	149.5	149.4	128.2	129.0	-
05502700	Yes	93.9	103.9	117.9	106.1	-	32.9	29.2	37.9	47.0	-	98.4	107.7	112.3	117.5	-
06908300	Yes	46.3	76.6	61.6	56.5	-	19.0	42.6	30.0	45.3	-	52.3	114.7	78.0	82.7	-
06910250	No	66.4	56.9	57.9	55.8	-	19.7	45.9	45.1	18.9	-	64.7	52.0	44.0	49.7	-
TENNESSEE																
03420360	Yes	53.0	49.3	47.3	-	47.0	22.8	25.2	36.4	-	24.6	56.5	56.6	66.3	-	60.2
03430400	No	39.4	70.8	41.6	-	52.6	22.2	154.1	91.3	-	70.6	33.3	189.5	90.6	-	89.1
03435030	No	39.8	56.8	61.9	-	33.1	58.8	70.7	67.4	-	87.9	66.1	115.0	104.8	-	74.8

calibrated parameter set.[4/] This definition allows a view of the effectiveness of the predicting relationships. Referring to Table 34, it can be shown that for the 20 sites tested, at least one set of either the LARGE, SMALL, region or state predicting equations met the above definition for 15 of the 20 sites with respect to VOLUME error, 13 of 20 for ROUTING, and 13 of 20 for TOTAL. The regional and state parameter sets produced the overall best results in attaining the above defined acceptable status. This does imply that the parameter values should be predicted with more than one predicting equation in order to allow the establishment of upper and lower bounds.

The second approach to verification is an attempt to visualize how these predicted parameters would perform as a means to produce flood frequency information. As mentioned, the derivation of flood frequency relationships has been the major use of the Model through the extension of flood peak records at gaged sites for the USGS-FHA program. Thus a comparison of flood frequency predictions between calibrated and predicted parameters would serve as a measure of how the predicted parameters would perform. A study initiated by R. W. Lichty derived flood frequency relationships which included Model parameters (Lichty and Liscum, 1977). The equation derived is of the form,

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[4/] A similar approach has been used by Ibbitt (1970) for judging acceptance of calibrations. Selection of a value to measure the acceptable difference between model application errors (10 percent for this study) is arbitrary.

$$Q_n = KA^{b_1} LAG^{b_2} FRVART^{b_3} C^{b_4} \quad \text{(VII.25)}$$

where Q_n is the flood peak determined from observed records with a recurrence interval of n-years, K is a regression constant, A, LAG and FRVART have been defined previously, C is an index to the effect of climate[5/], and b_1, b_2, b_3, b_4 are exponent values determined by multiple regression techniques. The values for Q_n were computed using procedures recommended by the U.S. Water Resources Council (1976) for 98 basins in the same study area. A total of 75 of these sites were also common to this study; 37 of these were part of the LARGE sample. These sites are indicated on Table D.1 of Appendix D. This data set of 75 sites was then used to derive regression equations in the form of equation (VII.25) for recurrence intervals of 1.25, 2, 5, 10, 25, 50 and 100 years for both the calibrated parameters and the predicted parameters. In order to judge the different sets of parameter predicting equations, these 75 sites were considered by forming five samples. All 75 sites were considered as a sample and the parameter values were predicted with the

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5/ The Model was used to generate 50 synthetic annual flood series using data from 33 National Weather Service rainfall sites. The 50 Model parameter sets were selected to cover the range of values experienced in the calibration process. A flood frequency curve was developed for each annual series. A regression model of the form, $q_n = aLAG^{b_1} * FRVART^{b_2}$, where q_n is the synthetic flood peak with recurrence interval of n-years, in cubic feet per second per square mile, LAG and FRVART are defined previously, a is a regression constant, and b_1 and b_2 are the coefficients, was developed. The regression constant, a, varies from site to site in such a manner that it was interpreted as reflecting the spatially varying influence of climate, and was defined as C (Lichty and Liscum, 1977).

LARGE equations. The 39 of these sites which were located in the SOUTH region were considered as the second sample and their parameter values were predicted with the SOUTH equations. Similarly, the 26 sites of the NORTH region, the 12 sites in Georgia and the 16 sites in Illinois were considered as separate samples with their parameter values determined by use of the appropriate prediction equations.

The values of K, b_1, b_2, b_3, and b_4 were determined for each of these five samples for both the calibrated and predicted parameter values. Table 35 gives these values for each n-year recurrence interval and statistics for judging the regression model. These statistics were computed to measure the amount of agreement between the value of Q_n based on observed data and the Q_n value determined from the regression model, and included the multiple correlation coefficient, MCC,[6/] standard error of estimate, SEE[7/] and percent variance explained, % VAR EXPLN.[8/] Comparison of these values for the same sample between

[6/] The multiple correlation coefficient, MCC, may be viewed as a simple correlation coefficient between the observed values, Y, and the values predicted from the regression equation, Y', because Y' can be viewed as a single independent variable constructed from the regression equation.

[7/] The standard error of estimate, SEE, is defined as

$$\text{SEE} = \sqrt{\frac{\Sigma\ (Y - Y')^2}{N}}$$

where Y and Y' are defined above, and N is the sample size.

[8/] The percent variance explained, % VAR EXPLN, is the ratio, expressed in percent, between the variation in the observed values, Y, explained by the combined linear influence of the independent variables and the total variation in Y. It is given by

$$\%\ \text{VAR EXPLN} = 100.0 * \text{MCC}^2.$$

Table 35. Information on Regression Model to Predict Flood Peak with Recurrence Interval of n-years Developed for Both Calibrated and Predicted Parameter Values

Sample ID Remarks	n-yr	Const. K	Regression Coefficients for A	LAG	FRVART	C	MCC	SEE	% VAR EXPLN
Large Sample:									
Calibrated	1.25	-.242	1.055	-1.002	-.430	1.045	.942	.181	88.8
Parameters	2	.512	1.006	-.890	-.328	.837	.961	.140	92.3
for	5	1.059	.967	-.781	-.224	.715	.963	.134	92.7
75	10	1.273	.949	-.723	-.169	.681	.957	.144	91.5
Common	25	1.438	.932	-.662	-.110	.671	.946	.164	86.5
Sites	50	1.517	.922	-.622	-.072	.675	.938	.179	87.9
	100	1.569	.914	-.586	-.037	.687	.929	.194	86.3
Predicted	1.25	.269	.954	-.920	-.473	.791	.890	.294	70.5
Parameters	2	1.025	.909	-.776	-.353	.584	.876	.244	76.8
for	5	1.569	.876	-.639	-.234	.466	.900	.216	81.0
75	10	1.776	.863	-.572	-.175	.435	.905	.211	82.0
Common	25	1.932	.852	-.504	-.110	.431	.905	.214	82.0
Sites	50	2.004	.847	-.461	-.069	.439	.903	.222	81.5
	100	2.047	.843	-.424	-.032	.456	.899	.230	80.8
South Sample:									
Calibrated	1.25	1.321	1.116	-1.142	-.456	.425	.945	.161	89.3
Parameters	2	.945	1.033	-.940	-.343	.664	.966	.121	93.3
for	5	.463	.957	-.745	-.225	.951	.968	.117	93.8
39	10	.178	.920	-.647	-.162	1.116	.962	.130	92.6
Common	25	-.156	.882	-.544	-.093	1.304	.951	.153	90.5
Sites	50	-.389	.859	-.478	-.047	1.434	.943	.171	88.9
in South	100	-.607	.839	-.420	-.006	1.554	.934	.189	87.3

Table 35. continued

Sample ID Remarks	n-yr	Const. K	Regression Coefficients for A	LAG	FRVART	C	MCC	SEE	% VAR EXPLN
South Sample continued									
Predicted	1.25	1.438	1.219	-1.529	-.266	.503	.883	.231	77.9
Parameters	2	1.046	1.124	-1.254	-.190	.725	.924	.179	85.5
for	5	.540	1.045	-1.003	-.112	.999	.948	.149	89.9
39	10	.240	1.010	-.883	-.070	1.159	.951	.149	90.3
Common	25	-.113	.978	-.762	-.023	1.346	.946	.161	89.6
Sites	50	-.359	.960	-.688	.008	1.474	.941	.174	88.5
in South	100	-.590	.944	-.623	.035	1.594	.934	.189	87.2
North Sample:									
Calibrated	1.25	-3.616	1.041	-.907	-.384	2.616	.929	.196	86.3
Parameters	2	-1.733	1.034	-.849	-.273	1.898	.941	.175	88.6
for	5	-3.404	1.036	-.806	-.175	1.250	.943	.173	88.9
26	10	.808	1.035	-.786	-.131	.927	.941	.179	88.5
Common	25	1.674	1.038	-.772	-.085	.593	.937	.188	87.7
Sites	50	2.209	1.039	-.763	-.059	.385	.933	.195	87.1
in North	100	2.671	1.040	-.755	-.037	.206	.930	.202	86.5
Predicted	1.25	-5.150	1.034	-.982	-.682	3.220	.918	.210	84.4
Parameters	2	-3.268	1.074	-1.036	-.570	2.517	.942	.174	88.8
for	5	-1.588	1.112	-1.097	-.469	1.892	.950	.163	90.3
26	10	-.759	1.137	-1.122	-.426	1.580	.949	.166	90.1
Common	25	.083	1.161	-1.158	-.380	1.263	.946	.174	89.5
Sites	50	.606	1.174	-1.175	-.355	1.064	.942	.181	88.8
in North	100	1.056	1.184	-1.190	-.332	.894	.939	.189	88.1

Table 35. continued

Sample ID Remarks	n-yr	Const. K	Regression Coefficients for A	LAG	FRVART	C	MCC	SEE	% VAR EXPLN
Georgia Sample:									
Calibrated	1.25	4.652	1.079	-.902	-.454	-1.081	.979	.113	95.9
Parameters	2	3.911	.922	-.594	-.292	-.690	.993	.056	98.6
for	5	3.125	.783	-.309	-.140	-.278	.976	.100	95.2
12	10	2.714	.716	-.169	-.065	-.062	.952	.141	90.6
Common	25	2.290	.647	-.024	.011	.161	.921	.188	84.8
Sites	50	2.009	.605	.067	.059	.308	.900	.218	80.9
in Georgia	100	1.757	.568	.147	.102	.440	.882	.246	77.8
Predicted	1.25	4.911	1.010	-.825	-.185	-1.125	.948	.177	89.9
Parameters	2	3.739	.910	-.585	.070	-.515	.975	.107	95.1
for	5	2.454	.834	-.383	.317	.148	.985	.078	97.1
12 Common	10	1.749	.804	-.294	.440	.511	.979	.093	95.9
Sites	25	.983	.776	-.210	.577	.907	.966	.124	93.3
in Georgia	50	.476	.761	-.159	.663	1.168	.955	.149	91.2
	100	.053	.749	-.119	.738	1.409	.944	.171	89.2
Illinois Sample:									
Calibrated	1.25	-8.603	.923	-.639	-.369	4.869	.960	.133	92.1
Parameters	2	-5.248	.955	-.720	-.336	3.470	.956	.134	91.3
for	5	-2.224	.992	-.803	-.304	2.214	.946	.148	89.4
16	10	-.814	1.004	-.837	-.291	1.012	.930	.170	86.5
Common	25	.648	1.021	-.878	-.276	1.012	.930	.170	86.5
Sites	50	1.519	1.029	-.900	-.269	.648	.925	.178	85.6
in Illinois	100	2.259	1.036	-.916	-.216	.340	.920	.185	84.7

Table 35. continued

Sample ID Remarks	n-yr	Const. K	Regression Coefficients for A	LAG	FRVART	C	MCC	SEE	% VAR EXPLN
Illinois Sample continued									
Predicted	1.25	-11.340	.809	-.304	-.060	6.166	.926	.179	85.7
Parameters	2	-8.766	.857	-.394	-.075	5.124	.920	.178	84.6
for	5	-6.536	.909	-.483	-.087	4.225	.908	.190	82.4
16	10	-5.442	.927	-.520	-.094	3.781	.900	.199	80.9
Common	25	-4.358	.951	-.565	-.099	3.343	.890	.211	79.3
Sites	50	-3.694	.963	-.587	-.104	3.073	.884	.218	78.2
in Illinois	100	-3.123	.972	-.604	-.107	2.841	.879	.225	77.3

calibrated and predicted forms of LAG and FRVART at 2-year and 50-year recurrence intervals show that the values of MCC and SEE for the calibrated parameters are either superior or at least equal to those for the predicted parameters at the 2-year level. However, these measures do not indicate such overall superiority at the 50-year level where the predicted parameters are shown to be superior for two samples, and approximately equal for another. This is attributed to the relatively poorer prediction of the parameters involved in FRVART as indicated by Table 33. Table 35 also shows that MCC increases and SEE decreases for both parameter determinations as the sample size decreases. This is to be expected. Another comparison shows that the trends of the change in the regression constants and the coefficients are similar for both parameter determinations in all samples except for LAG in the NORTH sample and FRVART in the ILLINOIS sample. Examination of the goodness of fit, % VAR EXPLN, shows that equation (VII.25) based on either predicted or calibrated parameter values accounts for 70.5 to 98.6 percent of the total variation in the observed Q_n values. Comparisons of % VAR EXPLN within each of the five samples indicate that use of the predicted parameters exhibit a fit to the observed Q_n which closely approximates or exceeds that shown for the calibrated parameters for four of the samples and all of the recurrence intervals. These comparisons indicate that the predicted parameters can be used with equation (VII.25) to produce results equivalent to those produced using the calibrated parameters. This statement appears to be more accurate when applied on a regional or state basis.

The verification process has tested the predicted parameters with respect to their reproduction of the calibrated parameters, the reproduction of Model results, and the results of an application to flood frequency determination. With respect to the first two, the predicted parameters demonstrated, for the most part, some level of agreement with the calibrated parameters, and they reproduced Model results within acceptable bounds. The final portion of the verification process showed that the predicted parameters could produce flood frequency results comparable to those produced by the calibrated parameters. For these reasons, the prediction equations for the parameters and their application procedure are considered to be acceptable. Thus, their application on ungaged sites within this study area should yield acceptable parameter values. However, the use of more than one applicable set of relationships is recommended to insure approximate bounds on the parameter values.

Summary

This chapter has presented the development, application procedure and verification process applied on the relationships used to predict parameter values for PSP, KSAT, RGF, BMSM, KSW and TC. These are briefly summarized below.

The development of the relationships depended on the use of 10 dependent variables, PSP, KSAT, RGF, BMSM, FRWET, FRDRY, FRVART, KSW, TC and LAG, and the 30 independent variables, discussed in Chapter V, and their combinations. The use of logarithmic transforms was found to be desirable for the determination of these relationships by multiple regression techniques for all but the one dependent variable, RGF. Relationships were developed for eight samples within the total sample size of 124. These included the complete set (LARGE), a set contained within the complete set (SMALL), regional sets (NORTH and SOUTH) and state samples (GEORGIA, ILLINOIS, MISS and TENN).

The development of equations for 10 dependent variables required a procedure to apply the equations so that the values of the 6 required parameters would be produced. The procedure developed was based on the demonstrated interaction by PSP and KSAT in Chapter VI. Thus, PSP and KSAT were computed to be compatible with FRWET. RGF and BMSM were computed from their equation forms as was KSW and TC. However, TC was compared with the TC-value resulting from the relationship for basin lag time, LAG, to insure that unrealistically low values were not given TC.

The verification of those equations and this procedure was approached with a two step process. First, the predicted parameters were investigated as to their agreement with the calibrated parameters and the manner in which they compared to the calibrated parameters for reproducing Model results. Second, the predicted parameters were compared to the calibrated parameters with respect to how they produced flood frequency information given the regression model form containing five of the six parameters. The results of this verification process form a basis for accepting these equations and the application procedure with the apparent need to apply more than one set of predicting equations to establish bounds for the subsequent parameters.

CHAPTER VIII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study has been to develop relationships between the Model parameters and physical basin characteristics and test the prediction of parameter values for ungaged sites. The study has been conducted using Model parameters determined endogenously by calibration with observed rainfall, runoff and evaporation data. The data base was the result of a USGS-FHA program conducted over the six state study area. Certain basin characteristics were also available from the USGS-FHA program. This study expanded the number of measured basin characteristics by a factor greater than three. Thus, prior to developing the relationships desired, the other main tasks of this study were to evaluate the available Model calibrations and complete the determination of an expanded set of basin characteristics.

Evaluation of Available Model Calibrations

In order to develop the desired relationships, values for the Model parameters had to be determined by calibrations. The calibrations were evaluated to insure that the resulting parameter values were applicable to this study. The evaluation process encompassed the determination of Model parameter significance, inspection of the process used to accomplish the calibration, and selection of sites whose Model calibrations were used to develop the relationships.

Parameter significance was defined in terms of the parameters sensitivity as measured by changes in Model output relative to changes in the parameter. The investigation into parameter sensitivity established a hierarchy of parameter sensitivity over various Model outputs. This allowed the determination of insensitive parameters, TP/TC and DRN. It was also found that in producing storm peaks and volumes, the runoff producing parameters, KSAT, PSP, EVC and RGF, demonstrated decreasing sensitivity as storm event size increased, whereas the routing parameters exhibited a much more constant sensitivity regardless of storm size. BMSM was shown to have nonlinear sensitivity for peaks and volumes, and high sensitivity with respect to moisture storage. BMSM was considered significant.

The process used to accomplish the calibration was inspected with respect to the fitting technique applied, the measure of agreement between the observed and modeled outputs, and the composition of the data set for which the calibration was performed. The Rosenbrock fitting technique was compared with two other automatic fitting techniques and was found to be equivalent in terms of its ability to locate the optimum and its speed in doing so. Parameter interaction was decreased by fixing four parameter values, DRN, EVC, RR and TP/TC. The Rosenbrock technique removed the effects of interaction except in the case of PSP and KSAT in which it tended toward an optimal value of PSP * KSAT. The objective function used was inspected and found to be superior, or at least equal, to others tried. The results of the sensitivity analysis implied that data set composition had to be evaluated as parameters insensitive to the storm events composing a data set could not be properly calibrated.

A selection process was developed in order that sites with acceptable calibrations would become the data base for developing the desired relationships. This process has three steps. First, the errors of the calibration as measured by the three objective functions of Chapter II were judged against standards established by considering all available calibrations. Second, the calibration was judged with respect to how the parameters reproduced the observed peaks. The resulting scatter diagram of observed versus computed peaks was represented by a simple linear regression model. Statistical tests were then performed on the coefficients of this simple model and other measures of the two peak series, mean, variance and correlation coefficient. Finally, a distribution of the size of storm events which was required to insure that all parameters would be adequately determined was assumed. The selection process involved the testing of each available calibration against these three criteria. The results of this process were two samples. One, chosen by requiring that only two of the criteria had to be satisfied, yielded a sample size of 124 sets of calibrated parameters (LARGE). The other required that all three criteria be met, and it yielded a sample size of 36 (SMALL).

The determination of these sample sizes, LARGE and SMALL, was the result of the entire process to evaluate the Model calibration. The sites within these samples provided the parameter values required as dependent variables for this study.

Determination of an Expanded Set of Basin Characteristics

The basin characteristics available from the USGS-FHA program were not sufficient for this study. It was assumed that a more complete set was needed to better describe the drainage basin in terms of its physical dimensions, its soils coverage, and its precipitation input. Thirty basin characteristics were determined for each site.

A total of 17 basin characteristics, six of which were available from the previous studies, which described the drainage basin in terms of size, shape, length, width, topography and other physiographic measures, were used in this study. Of these 17, nine, L, S, RRAT, SHAPE, OVL, OVS, LCHAN, DD, and F, either alone or in combination with another, were used as independent variables for both runoff producing and routing parameters. The fact that 6 of these nine had not been previously determined emphasizes the desirability of expanding the basin characteristics data set. These values were determined as either a single measure assumed to be indicative for the entire basin or an averaged value computed from several readings. In both cases, these lumped values which do not show the distribution of the characteristic over the basin were considered as adequate due to the lumped nature of the Model parameters and the basin avaeraging function inherent to their definition. The easy determination of these characteristics from topographic maps makes it possible to determine acceptable values.

Ten soils characteristics, none of which had been available previously, were determined for each site by determining the percent of the total drainage area which was covered by particular soil types, and how these soil types responded in the infiltration process. Seven of these, DBR, AVE AWC, AHOR PERM, HSG INFIL, MEAS KUN, MEAS PS and MEAS RGF3B or their combinations, were used as independent variables for runoff producing parameters. The assumptions made to determine these values were necessary due to the lack of sufficient specific soils data. The values were determined by assuming point values were representative of basin wide distribution of a soils characteristic. This was necessary due to the limited availability of soils data.

Three climatic characteristics were used with this study, and only one had not been determined previously. U.S. Weather Bureau publications were used to determine each of these three, MN PRECIP, I24,2 and I24,50. Two, MN PRECIP and I24,2, or in combination with others, were used as independent variables for runoff producing parameters as an index to moisture availability.

Of the 30 basin characteristics developed, a total of 18, either alone or in combination with another, were used in the final set of independent variables. It is concluded that this final set of independent variables was acceptable since the basin averaged values are compatible with the lumped nature of the Model, and also the independent variables tend to have an intuitive hydrologic relationship with the resultant dependent variables.

Relationship Development and Verification

The development of relationships for 10 dependent variables, PSP, KSAT, RGF, BMSM, FRWET, FRDRY, FRVART, KSW, TC and LAG, was accomplished by the use of multiple regression techniques. An application procedure was adopted to predict the 6 parameter values PSP, KSAT, RGF, BMSM, KSW and TC, from these 10 variables. The other 4 parameters, DRN, EVC, RR and TP/TC, were determined as previously explained with DRN, RR and TP/TC set at constant values and EVC determined from a U.S. Weather Bureau publication. A verification process was performed to assess these predicted parameter values.

Multiple regression techniques were applied to the selected parameter sets according to their presences in any or all of four groupings, LARGE, SMALL, two regions (NORTH and SOUTH) and four states (GEORGIA, ILLINOIS, MISS, TENN). The equations were developed to insure that the independent variables selected for a dependent variable were compatible among these four groupings. It was concluded from preliminary attempts that the use of logarithmic transforms applied to both dependent and independent variables produced the best results for all the dependent variables except RGF. The resulting equations and their statistics showed that the routing parameters had more favorable statistics. It is concluded that this is attributed to three facts. First, the routing component is more easily defined and, thus, more easily modeled than the runoff producing components. Second, direct observed data is available for calibration of the routing parameters whereas the infiltration-moisture accounting processes have not yielded directly observed data. Finally, the basin characteristics used to predict the routing parameters are more accurate than those soils characteristics required to predict the runoff producing parameters.

The application procedure adopted required that the values for

PSP and KSAT be compatible with FRWET. FRWET was chosen due to the recognition of interaction between PSP and KSAT. TC is determined from its relationship, and checked against the value determined for TC from LAG; it is only computed from the LAG equation if the value from the TC equation is less than the value of TC from the LAG equation. The other parameters are computed from their particular relationship. This procedure was found to be the most acceptable and this is attributed to the fact that it allows the determination of values for the highly sensitive PSP and KSAT which are compatible with their demonstrated interaction, and TC is insured of not being less than a demonstrated lower value.

The verification process was necessary to decide whether or not these predicted parameter values could be used with the Model at ungaged sites and produce acceptable results. This process consisted of two approaches. First, the predicted parameters were tested as to how well they agreed with the calibrated parameters in terms of what would be expected from the calibration process. Thus, the predicted values were compared with the calibrated values, and the results from the Model for the period of record used in calibration were compared for these two sets of parameters. These comparisons showed that the differences between Model results with the predicted parameters and those with the calibrated parameters for the calibration period were not large enough to not accept the predicted parameter sets. The application of more than one set of relationships was recommended as a mechanism for approximating bounds on the predicted parameter values.

The second approach to verification compared the flood frequency results using the predicted parameters with those produced by a similar method for the calibrated values. It was shown that the predicted parameters yielded comparable results, especially for those relationships developed for the states or regions.

Conclusions

The main objective of this study was the determination of a methodology for relating the Model parameter values to measurable physical watershed characteristics. This objective has been accomplished. It is concluded that the relationships developed and the application procedure produced acceptable parameter values for the study area. These values should be reviewed prior to application, and it is suggested that the use of each applicable set of equations, i.e., complete sample, region and state, would serve this purpose. The predicted values are found to be meaningful in both a physical and practical sense. They are physically meaningful in that the range of values produced agrees with the range produced by the calibrated parameters. Due to the imperfections in the modelling process, the presence of physical meaning may not be as important as the fact that the results produced are acceptable compared to those produced by the calibrated parameters. For these reasons, it is feasible for these predicted parameters to be applied in the Model at ungaged sites in this study area.

Recommendations for Further Study

This study has centered on the development of these relationships which are limited to this six state study region of Alabama, Georgia, Illinois, Mississippi, Missouri and Tennessee. As a first attempt to relate the parameters of this Model, several areas of interest have been established which could be investigated in future studies. There are also other investigations which could benefit from this study.

There are two main areas of interest which have been established by this study. The first of these is the extension of this approach to other areas. If possible, this would include the development of relationships for smaller physiographic regions within this study area. These regions could involve a particular state or several states. Such a study is a natural outgrowth of this one, and allows the opportunity to continue the verification of this approach to Model parameter determination. It would be of particular interest to determine whether or not equations involving the same independent variables would result. Such results have not been shown in similar studies on the Kentucky Watershed Model (Ross, 1970; Ambarauch and Simmons, 1973; Maggette et al., 1976). If different independent variables did result, it would also be of interest to see how equations involving the same independent variables from this current study would compare with the new.

The second main area of interest involves the continuation of the current study in order to investigate simplifying the parameter prediction equations. It is recognized that the method of insuring that each of the eight equations for a dependent variable has the same independent variables allows for possible improvement of some of the eight equations for some of the dependent variables. This continuation study could investigate whether or not reducing the number of independent variables reduces or increases the error in predicting parameter values. It could also investigate how much the Model accuracy improves using parameters determined by the prediction equations as opposed to parameters set equal to the statistical mean value from the entire study area, the particular region and state, and, if possible, a smaller physiographic region within the state. The added accuracy of the predicting equations could then be evaluated with respect to the use of mean values on the basis of extra effort required to determine the required basin characteristics.

There have been several other areas alluded to in this study which would be of interest. One of these would involve a systematic use of split sampling methods for calibrations on a large scale. Such a study, though expensive, would allow even tighter controls on the calibrated parameter values. It could be accomplished by calibrating over one sample and verifying over another, and repeating for each sample. The variation between samples and between each sample and the entire sample could be determined. This variation could be used to judge the advantage gained from the use of split samples.

Second would be an investigation into soils characteristics to determine how representative point values are of basin averages, and, in general, how their accuracy could be improved. The investigation would require approaches in two ways. First, the basin average values as computed by the grid sampling method could be compared to values computed using a much more detailed grid. This would involve application of the same approach mentioned in Chapter V, but in much greater detail. The other way to aid the investigation would require the determination of more comprehensive statistics regarding the variation of soils characteristics for a particular soils. This would involve a more extensive set of soils data to determine the required statistics.

A third area would be the continued investigation of the calibration set composition with respect to parameter sensitivity. This would be approached by the use of split sampling techniques to show how the parameter values vary when calibrated over various samples. The samples would be composed of (1) events for which parameter was sensitive, (2) events for which parameter was not sensitive, and (3) mixture of events for which parameter was and was not sensitive. The variation shown should illustrate the amount which a parameter could be in error if not calibrated over a data set containing the correct range in storm event types.

A final type study could compare the prediction of flood frequency information using predicted parameters versus not only calibrated parameters but other regression model approaches as well. This comparison would involve the development of the regression models using the estimates of flood frequency from observed estimates. A regression model involving physical measures of LAG and FRVART rather than the parameter estimates of Chapter VII would be attempted. In addition, other basin characteristic based regression models would be tried.

The results of the study reported in this dissertation could also be applied to aid other investigations which would employ a different version of the Model. The specific form of the Model would be a distributed version as the determination of parameter values by predicting equations involving measurable basin characteristics allows the watershed to be divided into smaller homogenous parts.

Two examples of possible application with a distributed version of the Model are presented. First, the actual attempt to define parameters for several homogenous areas within a basin would allow spatial variation of the parameters. This would, possibly, reduce errors present due to averaging parameters and basin characteristics over an entire basin. The second attempt would use the distributed version and redefine the parameter predicting equations to include more land use information. This would enable the predicting equations to serve as a planning management tool to study the effects of various land use changes on a basin. Of course, the incorporation of land use information could be used with the present version of the Model in the same manner. Such an approach was contemplated initially for this study, but sufficient land use data was not available on an acceptable scale. The use of a more concise study area may make this approach feasible.

APPENDIX A

PARTIAL LISTING OF USGS RAINFALL RUNOFF MODEL

THIS LIST SHOWS LOGIC FOR MODEL ONLY.
TREATMENT OF INPUT, OUTPUT AND INTERNAL CHECKS ARE ELEMENTED.
PERTINENT IDENTIFIERS ARE GIVEN.

USGS RAINFALL RUNOFF MODEL

```
/*-----------------------------------------------------------------------*/
/*     THE FOLLOWING IDENTIFIERS ARE DECLARED AS INTEGERS.               */
/*-----------------------------------------------------------------------*/
/*-----------------------------------------------------------------------*/
(
BDY,        /* BEGINNING DAY OF RAINFALL AND PAN EVAPORATION DATA,      */
BMO,        /* BEGINNING MONTH OF RAINFALL AND PAN EVAPORATION          */
            /* DATA.                                                    */
BTIME,      /* INTEGER VALUE OF UNIT DATA RECORDING INTERVAL.           */
BYR,        /* BEGINNINGYEAR OF RAINFALL AND PAN EVAPORATION            */
            /* DATA.                                                    */
CN,         /* CARD SEQUENCE NUMBER FOR VARIOUS DATA TYPES.             */
CODE,       /* CODE FOR VARIOUS DATA TYPES;                             */
            /*   1=UNIT RAINFALL,                                       */
            /*   2=UNIT DISCHARGE,                                      */
            /*   3=DAILY RAINFALL,                                      */
            /*   4=DAILY PAN EVAPORATION.                               */
DATE,       /* SEQUENCE DATE RELATIVE TO JANUARY 1, 1901=1.             */
DATERF,     /* SEQUENCE DATE OF START OF RECORD.                        */
DATEL,      /* SEQUENCE DATE OF END OF RECORD.                          */
DED,        /* USED IN READING DAILY EVAPORATION.                       */
DEL5,       /* NUMBER OF 5-MINUTE PERIODS IN UNIT RAINFALL              */
            /* RECORDING INTERVAL.                                      */
DPD,        /* USED IN READING DAILY RAINFALL.                          */
DY,         /* DAY OF OBSERVED RECORD.                                  */
ED(10),     /* ARRAY USED TO IDENTIFY END DAY OF PERIODS OF DAILY       */
            /* RAINFALL AND PAN EVAPORATION DATA.                       */
EDY,        /* ENDING DAY OF RAINFALL AND PAN EVAPORATION RECORDS.      */
EMO,        /* ENDING MONTH OF RAINFALL AND PAN EVAPORATION DATA.       */
EO,         /* NUMBER OF PARAMETERS IN MODEL.                           */
EYR,        /* ENDING YEAR OF RAINFALL AND PAN EVAPORATION RECORD.      */
DL950),     /* ARRAY USED TO IDENTIFY NUMBER OF DAYS IN EACH OF         */
            /* 50 OR LESS STORM PERIODS.                                */
FO,         /* NUMBER OF PARAMETERS TO BE FITTED IN CURRENT ROUND.      */
I,          /* GENERAL COUNTER.                                         */
I1,         /* GENERAL COUNTER.                                         */
#CYCLS,     /* THE NUMBER OF CONTINUOUS RECORDING PERIODS.              */
```

```
#FE,        /* THE NUMBER OF FLOOD PERIODS IN RECORD (25 OR LESS).     */
#FEA(50),   /* THE NUMBER OF FLOOD PEAKS (3 OR LESS) IN EACH OF        */
            /* 50 OR LESS FLOOD PERIODS.                               */
#UD(75),    /* ARRAY USED TO IDENTIFY THE SEQUENCE DATE OF 75 or       */
            /* LESS UNIT DISCHARGE DAYS.                               */
#UP(75),    /* ARRAY USED TO IDENTIFY THE SEQUENCE DATE OF 75 or       */
            /* LESS UNIT RAINFALL DAYS.                                */
J,          /* GENERAL COUNTER                                         */
JJ,         /* GENERAL COUNTER                                         */
K,          /* GENERAL COUNTER                                         */
K1,         /* GENERAL COUNTER                                         */
K4DAY,      /* GENERAL COUNTER                                         */
KE,         /* GENERAL COUNTER                                         */
KEA(50,3),  /* ARRAY USED TO DEFINE ENDING ELEMENT FOR EACH OF 3       */
            /* OR LESS FLOOD HYDROGRAPHS FOR EACH OF 50 OR LESS        */
            /* FLOOD PERIODS.                                          */
KS,         /* GENERAL COUNTER.                                        */
KSA(50,3),  /* ARRAY USED TO DEFINE STARTING ELEMENT FOR EACH OF       */
            /* 3 OR LESS FLOOD HYDROGRAPHS FOR EACH OF 50 OR LESS      */
            /* FLOOD PERIODS.                                          */
L,          /* GENERAL COUNTER.                                        */
LAGCT,      /* INDEX TO TEST FOR SUFFICIENCY OF TRANSLATION.           */
LEAP,       /* '1' OR '0' TO INDICATE LEAP YEAR.                       */
M,          /* INDEX USED IN ROSENBROCK ROUTINE.                       */
MN(13) INITIAL  (0,31,59,90,120,151,181,212,243,273,304,334,365),
            /* ARRAY USED TO COMPUTE SEQUENCE DATES.                   */
MO,         /* MONTH OF OBSERVED RECORD.                               */
NDELS,      /* UNIT DATA READS PER DAY.                                */
NK,         /* TOTAL NUMBER OF TRIALS IN ROUND OF FITTING.             */
NN,         /* IDENTIFIES OBJECTIVE FUNCTION;                          */
            /*   1=VOLUME ERROR FUNCTION,                              */
            /*   2=PEAK ERROR FUNCTION,                                */
            /*   3=PEAK AND VOLUME ERROR FUNCTION,                     */
            /*   4=ROUTING ERROR FUNCTION.                             */
NUDD,       /* NUMBER OF UNIT DISCHARGE DAYS IN CALIBRATION.           */
NUPD,       /* NUMBER OF UNIT RAINFALL DAYS IN CALIBRATION.            */
RODYS,      /* NUMBER OF DAYS START TO END OF RECORD.                  */
SD(10),     /* STARTING DAY FOR EACH PERIOD OF CONTINUOUS RECORD.      */
SIMOPT(3),  /* SWITCH ARRAY USED TO DEFINE DESIRED COMPUTATION         */
            /* OPTIONS.                                                */
TDELS,      /* NUMBER OF ELEMENTS IN TRANSLATION HISTOGRAM.            */
TESTA(50,3),/* SWITCH ARRAY INDICATING WHETHER OR NOT FLOOD EVENT      */
             /* WILL BE INCLUDED IN COMPUTATION OF ERROR FUNCTION.     */
UDD,        /* USED IN READING UNIT DISCHARGE DATA.                    */
UPD,        /* USED IN READING UNIT RAINFALL DATA.                     */
W,          /* DAY INDEX FOR COMPUTATION OF MODEL.                     */
YN(84) INITIAL
       (    0,  365,  730,  1095,  1461,  1826,  2191,
         2556, 2922, 3287,  3652,  4017,  4383,  4748,
```

```
           5113, 5478, 5844, 6209, 6574, 6939, 7305,
           7670, 8035, 8400, 8766, 9131, 9496, 9861,
          10227,10592,10957,11322,11688,12053,12418,
          12783,13149,13514,13879,14244,14610,14975,
          15340,15705,16071,16436,16801,17166,17532,
          17897,18262,18627,18993,19358,19723,20088,
          20454,20819,21184,21549,21915,22280,22645,
          23010,23376,23741,24106,24471,24837,25202,
          25567,25932,26298,26663,27028,27393,27759,
          28124,28489,28854,29220,29585,29950,30315),
            /* ARRAY USED IN COMPUTATION OF SEQUENCE DATES.          */
YR          /* YEAR OF OBSERVED RECORD.                              */
) FIXED BIN(31),

/*-----------------------------------------------------------------*/
/*-----------------------------------------------------------------*/
/*      THE FOLLOWING IDENTIFIERS ARE DECLARED AS REAL.            */
/*-----------------------------------------------------------------*/
/*-----------------------------------------------------------------*/
(
AREA,          /* USED IN COMPUTATION OF TRANSLATION HISTOGRAMS,    */
BMS,           /* VARIABLE USED IN SOIL MOISTURE ACCOUNTING.        */
BMSM,          /* PARAMETER INDICATING FIELD CAPACITY SOIL MOISTURE */
               /* STORAGE.                                          */
COEF,          /* FACTOR USED IN COMPUTATION OF INFILTRATION RATES. */
CUMAREA,       /* VARIABLE USED IN COMPUTATION OF TRANSLATION HISTO-*/
               /* GRAMS.                                            */
DA,            /* BASIN DRAINAGE AREA IN SQUARE MILES               */
DE(3653)       /* STORAGE ARRAY FOR DAILY PAN EVAPORATION RECORD.   */
DP(3653),      /* STORAGE ARRAY FOR DAILY RAINFALL RECORD.          */
DRN,           /* DRAINAGE FOR UNIT RAINFALL TIME INTERVAL.         */
DX4,           /* ROUTING COEFFICIENT FOR LINEAR RESERVOIR.         */
ETDEL,         /* POTENTIAL EVAPOTRANSPIRATION FOR TIME INTERVAL    */
               /* EQUAL TO UNIT RAINFALL DURATION.                  */
EVC,           /* PARAMETER USED TO ADJUST DAILY PAN EVAPORATION    */
               /* TO DAILY POTENTIAL EVAPOTRANSPIRATION.            */
EVCDEL,        /* PAN COEFFICIENT FOR COMPUTATION INTERVAL.         */
FPKA(50,3),    /* OBSERVED VALUE OF FLOOD PEAK FOR EACH OF 3 OR LESS*/
               /* PEAKS FOR EACH OF 50 OR LESS FLOOD PERIODS.       */
FR,            /* INFILTRATION CAPACITY (INCHES PER 5-MINUTES).     */
FVOLA(50,3)    /* OBSERVED VALUE OF FLOOD RUNOFF FOR EACH OF 3 OR   */
               /* LESS FLOOD HYDROGRAPHS FOR EACH OF 50 OR LESS     */
               /* FLOOD PERIODS.                                    */
I2CFSP,        /* CONVERSION FACTOR TO EXPRESS RUNOFF RATE IN CUBIC */
               /* FEET PER SECOND.                                  */
IMP_AREA,      /* PERCENT IMPERVIOUS AREA.                          */
IMP_RET,       /* IMPERVIOUS RETENTION (MAXIMUM VALUE IS 0.05 INCH).*/
INC,           /* DIFFERENCE BETWEEN DAILY RAINFALL AND DAILY EVAPO-*/
               /* TRANSPIRATION.                                    */
```

```
KSAT,            /* MINIMUM INFILTRATION RATE (INCHES PER 5-MINUTES).  */
KSW,             /* LINEAR RESERVOIR ATTENUATION (HOURS).              */
OF,              /* OBJECTIVE FUNCTION (BEST TO DATE).                 */
OFA(4),          /* ARRAY TO STORE VARIOUS OBJECTIVE FUNCTIONS.        */
PDEL,            /* UNIT RAINFALL RECORDING INTERVAL AS A FRACTION OF  */
                 /* A DAY.                                             */
PER_AREA,        /* PERVIOUS DRAINAGE AREA.                            */

PS,              /* VARIABLE USED IN COMPUTATION OF INFILTRATION RATE. */
PSP,             /* PARAMETER USED IN COMPUTATION OF INFILTRATION RATE. */
PTIME,           /* UNIT RAINFALL RECORDING INTERVAL (MINUTES).        */
PW,              /* DAILY RAINFALL.                                    */
QBA(50,3),       /* BASEFLOW DISCHARGE RATE FOR EACH OF 3 OR LESS      */
                 /* FLOOD HYDROGRAPHS FOR EACH OF 50 OR LESS FLOOD     */
                 /* PERIODS.                                           */
Q1,              /* USED IN COMPUTATION OF RUNOFF.                     */
Q2,              /* USED IN COMPUTATION OF RUNOFF.                     */
QI,              /* TRANSLATED RAINFALL EXCESS DURING ROUTING INTERVAL. */
QMAX,            /* MAXIMUM DISCHARGE OF FLOOD HYDROGRAPH.             */
QO,              /* COMPUTED DISCHARGE RATE.                           */
QR,              /* RAINFALL EXCESS (INCHES) FOR 5-MINUTE INTERVAL.    */
RF,              /* RAINFALL (INCHES).                                 */
RGF,             /* PARAMETER USED IN COMPUTING INFILTRATION RATES.    */
RR,              /* PARAMETER USED TO ACCOUNT FOR SURFACE RUNOFF FROM  */
                 /* DAILY RAINFALL DATA.                               */
U(4),            /* STORAGE ARRAY OF ERROR FUNCTIONS.                  */
U1,              /* VOLUME ERROR FUNCTION.                             */
U2,              /* PEAK ERROR FUNCTION.                               */
U3,              /* PEAK AND VOLUME ERROR FUNCTION.                    */
U4,              /* ROUTING ERROR FUNCTION.                            */
UU,              /* USED IN COMPUTATION OF ERROR FUNCTIONS.            */
X(30),           /* STORAGE ARRAY FOR PARAMETER VALUES.                */
XX,              /* INCREMENTED VALUE OF PARAMETER.                    */
SFPKA(50,3),     /* MAXIMUM COMPUTED DISCHARGE RATE FOR EACH OF 3 OR   */
                 /* LESS FLOOD PEAKS FOR EACH OF 50 OR LESS FLOOD      */
                 /* PERIODS.                                           */
SFVOLA(50,3),    /* COMPUTED VOLUME OF RUN OFF FOR EACH OF 3 OR LESS   */
                 /* FLOOD HYDROGRAPHS FOR EACH OF 50 OR LESS FLOOD     */
                 /* PERIODS.                                           */
SMS,             /* SOIL MOISTURE STORAGE IN WETTED LAYER.             */
SR,              /* RAINFALL DURING 5-MINUTE INTERVAL.                 */
SRV,             /* VARIABLE USED TO COMPUTE FLOOD RUNOFF.             */
STRA(50,3)       /* STORM RAINFALL FOR EACH OF 3 OR LESS FLOOD PEAKS   */
                 /* FOR EACH OF 50 OR LESS FLOOD PERIODS.              */
TARRAY(51),      /* TRANSLATION HISTOGRAM USED TO LAG INFLOW TO LINEAR */
                 /* RESERVOIR.                                         */
TC,              /* TIME OF CONCENTRATION.                             */
TIME,            /* VARIABLE USED IN COMPUTING TRANSLATION HISTOGRAMS. */
TP,              /* TIME TO PEAK OF MODEL TRANSLATION HYDROGRAPH.      */
```

```
TQ1(51)        /* STORAGE ARRAY USED TO LAG RAINFALL EXCESS.              */
) FLOAT DEC(6),
/*------------------------------------------------------------------------*/
/*------------------------------------------------------------------------*/
/*   THE FOLLOWING ARE DECLARED AS REAL, CONTROLLED ARRAYS.               */
/*------------------------------------------------------------------------*/
/*------------------------------------------------------------------------*/
(
SUD(NUDD),     /* STORAGE ARRAY FOR COMPUTED DISCHARGE RATES.             */
UD(NUDD),      /* STORAGE ARRAY FOR UNIT DISCHARGE DATA.                  */
UP(NUDD),      /* STORAGE ARRAY FOR UNIT RAINFALL DATA.                   */
UPE(NUDD)      /* STORAGE ARRAY FOR COMPUTED RAINFALL EXCESS.             */
) FLOAT DEC(6) CONTROLLED,
/*------------------------------------------------------------------------*/
/*------------------------------------------------------------------------*/
/*------------------------------------------------------------------------*/
/*     FOLLOWING CODE IS FOR USGS RAINFALL RUNOFF MODEL.                  */
/*------------------------------------------------------------------------*/
MOD1:
  IF SIMOPT(1)=1 THEN DO;
     PSP=X(1);
     IF PTIME  < 5 THEN KSAT = X(2)/60.0;
     ELSE KSAT = X(2)/12.0;
     DRN = X(2) * X(3) * PDEL * 24.0;
     RGF=X(4);
     BMSM=X(5);
     EVC=X(6);
     RR=X(7);
     COEF=(RGF-1.0)/BMSM;
     K=1;
     UPE=0.0;
     DO I1=1 TO #CYCLS:
        J=SD(I1);
        JJ=ED(I1);
        IMP_RET=0.0;
        SMS=0.0;
        BMS=0.5*BMSM;
     /* START DAY LOOP */
       DO W=J TO JJ;
          PW=DP(W);
          IF PW > =0.0 THEN DO;
             INC=PW*RR-EVC*DE(W);
             IMP_RET=IMP_RET+PW-EVC*DE(W);
             IF IMP_RET  < 0.0 THEN IMP_RET=0.0;
             IF IMP_RET > 0.05 THEN IMP_RET=0.05;
             BMS = BMS + SMS + INC;
             IF (BMS  < 0.0) THEN BMS = 0.0;
             SMS = 0.0;
             IF BMS>BMSM THEN BMS=BMSM ; END ;
```

```
      ELSE DO;
         ETDEL=PDEL*EVC*DE(W);
         K4DAY=K+NDELS-1;
         DO K=K TO K4DAY;
         IF  UP(K) < 0.005 THEN UP(K) = 0.0 ;
            RF=UP(K);
            IF RF>0.0 THEN DO:
               IMP_RET=IMP_RET+RF;
               Q2 = 0.0;
               IF IMP_RET > 0.05 THEN DO;
                  Q2=IMP_RET-0.05;
                  IMP_RET=0.05; END;
               Q1=0.0;
               SR = RF/DELS;
               IF SMS = 0.0 THEN DO;
                  PS = PSP * (RGF - COEF * BMS);
                  FR = KSAT * (1.0 + PS/SR);  END;
               ELSE FR = KSAT * (1.0 + PS/SMS);
               DO I = 1 TO DELS;
                  IF SR < FR THEN QR=SR**2/(2.0*FR);
                  ELSE QR=SR-FR/2.0;
                  SMS=SMS+SR-OR;
                  FR=KSAT*(1.0+PS/SMS);
                  Q1=Q1+QR; END;
               UPE(K)=Q1*PER_AREA+Q2*IMP_AREA; END;
          ELSE DO;
             IMP_RET=IMP_RET-ETDEL;
             IF IMP_RET  < 0.0 THEN IMP_RET=0.0;
             IF  (SMS-ETDEL) < 0.0 THEN DO;
                 BMS=BMS+SMS-ETDEL;
                 SMS=0.0;
                 IF BMS < 0.0 THEN BMS=0.0; END;
             ELSE SMS=SMS-ETDEL;
             IF SMS>DRN THEN DO:
                SMS=SMS-DRN;
                BMS=BMS+DRN; END;
             ELSE DO;
                BMS=BMS+SMS;
                SMS=0.0; END;
             IF BMS>BMSM THEN BMS=BMSM;
             END;
       END;  END;  END;  END;
U1=0.0;
J=0;
DO I=1 TO #FE;
   DO K=1 TO #FEA(I);
      SRV=0.0;
      KS=J+KSA(1,K);
      KE=J+KEA(I,K);
      DO L=KS TO KE;
         SRV=SRV+UPE(L); END;
```

```
        SFVOLA(I,K)=SRV;
        IF TESTA(1,K)=1 THEN DO:
           IF SRV  <= 0 THEN GO TO LERRLOG;
           IF FVOLA(I,K)  <= 0 THEN GO TO LERRLOG;
           UU=LOG(SRV)-LOG(FVOLA(I,K));
           U1=U1+UU*UU; END; END;
     J=J+NDELS*FD(I);  END;
 U(1)=U1; END;

IF SIMOPT(2)=1 THEN DO;
  SUD=0.0;
  KSW=X(8);
  TC=X(9);
  TP=X(10)*X(9);
  TDELS=TC/PTIME;
     IF TDELS>144 THEN TDELS=144;   /* SAVE BLOWING ARRAY  */
  CUMAREA=0.0;
  TIME=0.0;
  DO I=I TO TDELS;
     TIME=TIME+PTIME;
     IF TIME  <= TP THEN AREA=(TIME**2)/(TP*TC);
     ELSE AREA=(TP/TC) +( (2.0/(TC-TP)) * (TIME-((TIME**2)/(2.0*TC))
       -TP+((TP**2)/(2.0*TC))));
     TARRAY(I)=(AREA-CUMAREA)*I2CFSP;
     CUMAREA=AREA; END;
  IF CUMAREA < 0.99 THEN DO:
     TDELS=TDELS+1;
     TARRAY(TDELS)=(1.0-CUMAREA)*I2CFSP; END;
  ELSE TARRAY(TDELS)=TARRAY(TDELS)+(1.0-CUMAREA)*I2CFSP;
  DX4=EXP(-PTIME/(60.0*KSW));
  J=0;
  U2,U4=0.0;

     /*  CHANGED AREA  */
   DO I=1 TO #FE;
      DO K1=1 TO #FEA(I);
      LAGCT=TDELS+1;
      QO=0.0;
      TQ1=0.0;
         QMAX=0.0;
         KS=J+KSA(I,K1);
         KE=J+KEA(I,K1);
      DO K = KS TO KE;
         Q1=UPE(K);
         TQ1(1)=Q1;
         IF Q1 > 0.0 THEN LAGCT=1;
          IF QO  < .0001 THEN QO = 0.0 ;
         IF LAGCT > TDELS THEN QO=QO*DX4;
         ELSE DO;
            LAGCT=LAGCT+1;
            QI=0.0;
```

```
            DO L=TDELS TO 1 BY -1;
               QI=QI+TQ1(L)*TARRAY(L);
               TQ1(L+1)=TQ1(L); END;
            QO=QI-(QI-QO)*DX4; END;
         IF QO > QMAX THEN QMAX = QO;
         SUD(K)=QO;            END;
         SFPKA(I,K)=QMAX;
         IF TESTA(I,K1)=1 THEN DO;
            UU=LOG(QMAX)-LOG(FPKA(I,K1));
            U2=U2*UU*UU;
            UU=LOG(QMAX*FVOLA(1,K1)/SFVOLA(I,K1))-LOG(FPKA(I,K1));
            U4=U4+UU*UU; END; END;
      J=J+NDELS*FD(I); END;
   U(2)=U2;
   U(3)=U1+U2;
   U(4)=U4; END;

/*------------------------------------------------------------------*/
```

APPENDIX B

LISTING OF MODIFIED ROSENBROCK OPTIMIZATION ROUTINE.

IDENTIFIERS PERTINENT TO ROSENBROCK ARE GIVEN.

MODIFIED ROSENBROCK

```
/*-------------------------------------------------------------------*/
/*     THE FOLLOWING IDENTIFIERS ARE DECLARED AS INTEGERS.
/*-------------------------------------------------------------------*/
B3,           /* SWITCH SET EQUAL TO '1' TO SIGNAL END OF A ROUND      */
              /* OF FITTING.                                           */
#,            /* COUNTER USED IN ROSENBROCK ROUTINE TO IDENTIFY        */
              /* CURRENT SEARCH VECTOR.                                */
EO,           /* NUMBER OF PARAMETERS IN MODEL.                        */
M,            /* INDEX USED IN ROSENBROCK ROUTINE.                     */
OPT#(10),     /* ARRAY USED TO IDENTIFY THOSE PARAMETERS INCLUDED      */
              /* IN ROUND OF FITTING.                                  */
RITE,         /* '1' or '0' INDICATING WHETHER OR NOT END OF STAGE     */
              /* RESULTS ARE TO BE PRINTED.                            */
TRYCT,        /* USED IN ROSENBROCK ROUTINE TO RECORD CURRENT TRIAL.   */
/*-------------------------------------------------------------------*/
/*       THE FOLLOWING IDENTIFIERS ARE DECLARED AS REAL.              */
/*-------------------------------------------------------------------*/
A(0:110),     /* 'A' MATRIX USED IN ROSENBROCK METHOD OF FITTING       */
              /* PARAMETERS. THE POSITIONS A(11:110) ARE USED TO       */
              /* DEFINE THE SEARCH PATTERN, E.G., A 10*10 MATRIX       */
              /* OF VECTORS AND DIMENSIONS (PARAMETERS). THE FIRST     */
              /* TEN POSITIONS (1:10) ARE STEP-SIZE INCREMENTS TO      */
              /* BE APPLIED TO THE VARIOUS VECTORS. POSITION '0' IS    */
              /* ONLY USED FOR CONTINUITY AT START OF EACH STAGE.      */
B1,           /* USED IN ROSENBROCK ROUTINE TO REFLECT EFFICIENCY      */
              /* OF OPTIMIZATION PROCEDURE.                            */
B2,           /* SIMILAR TO B1.                                        */
BD,           /* VARIABLE USED IN COMPUTATION OF NEW SEARCH PATTERN.   */
D(0:10),      /* 'D' MATRIX USED IN ROSENBROCK ROUTINE TO RECORD       */
              /* CUMULATIVE INCREMENT FOR EACH SEARCH VECTOR DURING    */
              /* STAGE.                                                */
E(0:10),      /* SWITCHES USED IN OPTIMIZATION TO TEST FOR END OF      */
              /* STAGE CRITERION.                                      */
EPSILON,      /* PARAMETER OF ROSENBROCK ROUTINE DEFINING INITIAL      */
              /* STEP-SIZE INCREMENT (FRACTION).                       */
F(0:10),      /* SWITCHES USED IN OPTIMIZATION TO TEST FOR END OF      */
              /* STAGE CRITERION.                                      */
G(30),        /* ARRAY USED IN ROSENBROCK ROUTINE TO QUANTIFY LOWER    */
              /* LIMIT OF PARAMETER VALUE, ETC.                        */
```

```
GD,           /* VARIABLE USED IN ROSENBROCK ROUTINE.                       */
GOE,          /* VARIABLE USED IN ROSENBROCK ROUTINE.                       */
H(30),        /* ARRAY USED IN ROSENBROCK ROUTINE TO QUANTIFY UPPER         */
              /* LIMIT OF PARAMETER VALUE.                                  */
HD,           /* VARIABLE USED IN ROSENBROCK ROUTINE.                       */
SF,           /* USED IN ROSENBROCK ROUTINE.                                */
U(4),         /* STORAGE ARRAY OF ERROR FUNCTIONS.                          */
U1,           /* VOLUME ERROR FUNCTION.                                     */
U2,           /* PEAK ERROR FUNCTION.                                       */
U3,           /* PEAK AND VOLUME ERROR FUNCTION.                            */
U4,           /* ROUTING ERROR FUNCTION.                                    */
UU,           /* USED IN COMPUTATION OF ERROR FUNCTIONS.                    */
X(30),        /* STORAGE ARRAY FOR PARAMETER VALUES.                        */
XX            /* INCREMENTED VALUE OF PARAMETER.                            */
/*--------------------------------------------------------------------------*/
/*--------------------------------------------------------------------------*/
/*                FOLLOWING CODE IS FOR ROSENBROCK.                         */
/*--------------------------------------------------------------------------*/
INITIAL_OPT;
  DO I=1 TO EO;
   XX=X(I);
   IF XX >= G(I)  & XX  <= H(I) THEN X(EO+I)=XX;
                              ELSE DO; PUT PAGE EDIT
                ('COMPUTATION TERMINATING DUE TO BOUNDARY',
                'CHECK OF PARAMETER',I)(2 A,F(3));
                GO TO LRC1;
              END;
  END;
  DO I=1 TO EO;
    L=2*EO+I ;G(L),H(L)=0.0;
    K=EO+I;GOE=(H(I)-G(I))*0.0001;
    G(K)=G(1)+GOE;H(K)=H(I)-GOE;
  END;
  U=0.0;
  OFA=1E50;
  IHD=0;

  NEW_ROUND: /* GIVEN MODEL PHASE  */

       IF ITAB > NUMBRNDS THEN GO TO LRC1; /* COMPUTATION COMPLETE  */
                                  /*     GO TO NEXT STATION       */

       SWENTR = '1'; CALL READ_CD; /* LOAD COMPUTATION OPTIONS   */
  SIGNAL ENDPAGE (SYSPRINT);
  PUT EDIT
    ('BEGINNING OF STAGE - PHASE ',ITAB,
     'INITIAL PARAMETER VALUES ARE:')(A,F(1),SKIP(2),A;
      ITAB = ITAB + 1;  /* STEP TO PHASE 2 COMPUTATION */
```

```
NK=K*FO;
A=0.0;          E,F=0;TRYCT=0;B3=0;B1,B2=0.0;D=0.0;
L=FO+1;
   DO I= 1 TO FO;
     A(L*I) = 1.;
     J = OPT#(I);
     A(I) = X(J) * EPSILON;
   END;
J=1;
DO I =1 TO EO;
  PUT EDIT (I,(X(I)+0.00000005))  (SKIP,F(3),F(12,6));
  IF I=UPT#(J) THEN DO;PUT EDIT (' *') (A);J=J*1;END;
END;
PUT EDIT
  ('* - PARAMETERS TO BE OPTIMIZED')  (SKIP,A);
PUT EDIT
  (' INITIAL STEP-SIZE INCREMENTS***')  (SKIP,A);
PUT EDIT
  ((A(I) DO I=1 TO FO))  (SKIP,(FO)F(10,6));
PUT EDIT
         ('THE MAXIMUM NUMBER OF TRYCTS IS ',NK,
        'AT THE START OF EACH STAGE STEP-SIZE = ', EPSILON*100,
        ' % OF THE VECTOR SIZE.')
        (SKIP(3),A,F(4), SKIP(1),A,F(2),A);
#=0;
RITE=1;
IF NK=0 THEN B3=1;  /*   THIS INSURES OUTPUT IF TRYCTS PER PARAM.=0. */
GO TO MOD1;

              /* MODIFIED ROSENBROCK OPTIMIZATION */
RB01:
  OF=OFA(NN);
  UU=U(NN);IF UU > OF THEN GO TO OPT2;
  DO I=1 TO FO;
    M=OPT#(1);XX=X(M)  ;K=EO+M;L=2*EO+M;
    IF XX  < G(K) THEN DO;
      GD=(G(K)-XX)/(G(K)-G(1)); HD=UU=G(L);GO TO LL2;
    END;ELSE IF XX > H(K) THEN DO;
      GD=(XX-H(K))/(H(I)-H(K));HD=UU-H(L);
      LL2:  UU=UU+((-2*GD+4)*GD-3)*GD*HD;
            IF UU > OF THEN GO TO OPT2;
    END;
  END;
  OFA(NN)=UU;
  DO I=1 TO FO;
    M=OPT#(1);XX=X(M)  ;K=EO+M;L=2*EO+M;
    X(L)=XX;
    IF XX  <= H(K) THEN IF XX >= G(K) THEN
         G(L),H(L)=UU;
  END;
```

```
  F(#)=1;E(#)=0;
  D(#)=D(#)+A(#);
  A(#)=A(#)*3.0;
OPTP:
  IF TRYCT = 0 THEN DO:  SIGNAL ENDPAGE (SYSPRINT); PUT EDIT
   ('TRCT  OBJ. FUNC.    PSP        KSAT       DRN        RGF  ',
    '        BMSM      EVC        RR         KSW        TC       ',
    '    TP/TC') (SKIP(3),3 A);  END;
  IF IHD=1 THEN DO;
   IHD=0;
   SIGNAL ENDPAGE(SYSPRINT);
   PUT EDIT
   ('TRCT  OBJ. FUNC.    PSP        KSAT       DRN        RGF  ',
    '        BMSM      EVC        RR         KSW        TC       ',
    '    TP/TC') (SKIP(3),3A);
             END;
  PUT EDIT (TRYCT,U(NN),(X(I) DO I = 1 TO 10)) (SKIP,F(3),X(1),
                                                  11 F(11,5));
  IF TRYCT = NK THEN DO; B3,RITE=1; GO TO MOD1; END;
  GO TO OPT3;
OPT2:
  M=2*EO;
  DO I=1 TO FO:K=OPT#(I);X(K)=X(K+M);END;
OPT4:
  IF TRYCT=NK THEN DO: B3=1; RITE=1; GO TO MOD1; END;
  A(#)=-0.5*A(#);E(#)=E(#)+1;
  DO I=1 TO FO WHILE (E(I)*H(I) > 0);END;
  IF I > FO THEN GO TO OPT11;
OPT3:
  IF TRYCT = NK THEN DO;B3=1 GO TO OPTP;END;
  TRYCT=TRYCT+1;
  IF # = FO THEN #=1;ELSE #=#+1;
  DO I=1 TO FO;
    K=OPT#(1);XX=X(K)+A(FO*1+#)*A(#);
    IF XX > G(K) & XX  < H(K) THEN X(K)=XX;
      ELSE DO;
        L=2*EO;
        DO I=(I-1) TO 1 BY -1;
          K=OPT#(I);X(K)=X(K+L);
        END;
        GO TO OPT4;
      END;
  END;
  GO TO MOD1;
OPT11:
  DO I=1 TO FO;
    L=FO*(I+1);A(L)=D(FO)*A(L);K=FO*I;
    DO J=(FO-1) TO 1 BY -1;
      L=K+J;A(L)=D)J)*A(L)+A(L+1);
    END;
```

```
    END;
    BD=0.0;DO I=1 TO FO;BD=A(FO*I+1)**2+BD;END;
    B1=SQRT(BD);
    DO I=1 TO FO;L=FO*I+1;A(L)=A(L)/B1;END;
    SF=0.;
    DO I=1 TO FO;
      K=OPT#(I); L=FO*I+1; SF=SF+ABS(A(L))*X(K);END;
    A(1)=SF*EPSILON;
    BD=0.0;DO I=1 TO FO;BD=A(FO*I+2)**2+BD;END;
    B2=SQRT(BD)/B1;
    PUT EDIT(' ')  (SKIP(1),A);
    PUT EDIT ('B1=',B1,'B2=',B2) (SKIP,A,F(9,6));
    J=2;
    DO WHILE (FO > = J);
      K=1;BD=0.0;
      DO WHILE (K  < J);
        DO I=1 TO FO;L=FO*I;BD=BD+A(L+J)*A(L+K);END;
        DO I=1 TO FO:L=FO*I+J;A(L)=A(L)-A(L-J+K)*BD;END;
        K=K+1;BD=0.0;
    END;
    DO I=1 TO FO;BD=A(FO*I+J)**2+BD;END;
    BD=SQRT(BD);
    DO I=1 TO FO;L=FO*I+J;A(L)=A(L)/BD;END;
    SF=0.;
    DO I=1 TO FO;
      K=OPT#(I); L=FO*I+J; SF=SF+ABS(A(L))*X(K);END;
    A(J)=SF*EPSILON;
    J=J+1;
  END;
  PUT EDIT
    ('NEW ORTHONORMAL BASIS***')  (SKIP,A);
  PUT EDIT
    (((A(I*FO+J) DO J=1 TO FO) DO I=1 TO FO))
   (SKIP,(FO)F(8,5));
  #=0;
  PUT EDIT
    ('START OF STAGE STEP-SIZE INCREMENTS***',
     (A(I) DO I=1 TO FO)) (SKIP,A,SKIP,(FO)F(10,6));
  DO I=1 TO FO;
    D(I)=0.0;F(I)=0;
    K=OPT#(I);X(EO+K)=X(K);
  END;
    IHD=1;
    RITE=1; GO TO MOD1;

/*-----------------------------------------------------------------*/
```

APPENDIX C

The figures presented in this appendix are examples of typical responses of the Model as a single or logical pair of parameters were varied about their calibrated values while the remaining parameters were held at their calibrated values. The ordinate for these figures represents either a specific output, such as a storm event peak discharge, or an objective function value which was computed over a data set containing several storm events. For each figure, the abscissa represents the variation in a single parameter or a logical pair of parameters by using the ratio of the parameter value used to compute the corresponding ordinate value to the actual calibrated parameter value. This type of abscissa allows all of the parameters to be plotted on the same scale. These figures may be subdivided into four classes.

The first class presents various outputs for a single storm event as a single parameter is varied about its calibrated value. The variation in the output shown for each parameter is indicative of the parameter's sensitivity for that particular output and storm event. Figures C.1 through C.17 are members of this class. Figures C.1 through C.3, and C.7 through C.9 show how the peak discharge value varies for a single event as each of the ten parameters are varied individually. Similarly, figures C.4 through C.6 show how the runoff volume varies for a single event. Variation of the values for four moisture storage measures for a single event as an individual parameter varies is shown in Figures C.10 through C.17. Only the parameters concerned with the runoff volume producing portion of the Model were varied for the figures concerned with moisture storage. The four moisture storage measures studied were the value for BMS on the day previous to the storm event, the average value of BMS for the storm event, the average value of SMS for the storm and the value for BMS on the day after the event.

The second class of figures presents an output for a single storm event as a parameter varies about its calibrated value alone or in conjunction with another parameter. The pairing of the parameters is restricted to only logical pairs such that parameters from the runoff producing portion of the Model were paired only with each other and the parameters from the routing portion of the Model were paired only with each other. The output for this class of figures was the peak discharge value for a storm event. The variation in the peak due to the change in a parameter compared to the variation in the peak due to the change in each of a logical pair of parameters allowed for the investigation of interaction between parameters. An indication of how this interaction would effect peak discharge values for specific storm events was available from these figures. This class is composed of Figures C.18 through C.25.

The third class of figures presents the variation of an objective function value as a parameter varies about its calibrated value alone or in conjunction with another parameter. As with the second class of figures, the pairing of the parameters is restricted to only logical pairs. The objective function value is computed with use of equation (II.15) for the storm events used in determining the calibrated parameters. Similar to the figures in the second class, these figures indicated the effects of interaction between parameters on the objective function value computed for a site. However, these effects of interaction are only comparable with the same distribution of storm events. Figures C.26 through C.33 belong to this class.

The fourth and final class of figures presents a means for comparing various objective function forms. These figures show varying values for five separate objective function forms computed over an identical data set as a single parameter varies about its calibrated value. The five objective function forms are defined in equations (VI.1) through (VI.5). The five may be summarized as (1) the sum of squared differences between observed and modeled peaks for logarithmic transforms, (2) sum of squared differences using no transform, (3) sum of relative differences squared, (4) sum of squared differences using square transform, and (5) sum of the absolute value of differences. The use of each of the Model's ten parameters allowed a comparison to be drawn not only between the different objective function forms but also between the sensitivity exhibited by the different objective function forms for the various parameters. Figures C.34 through C.43 belong to this class.

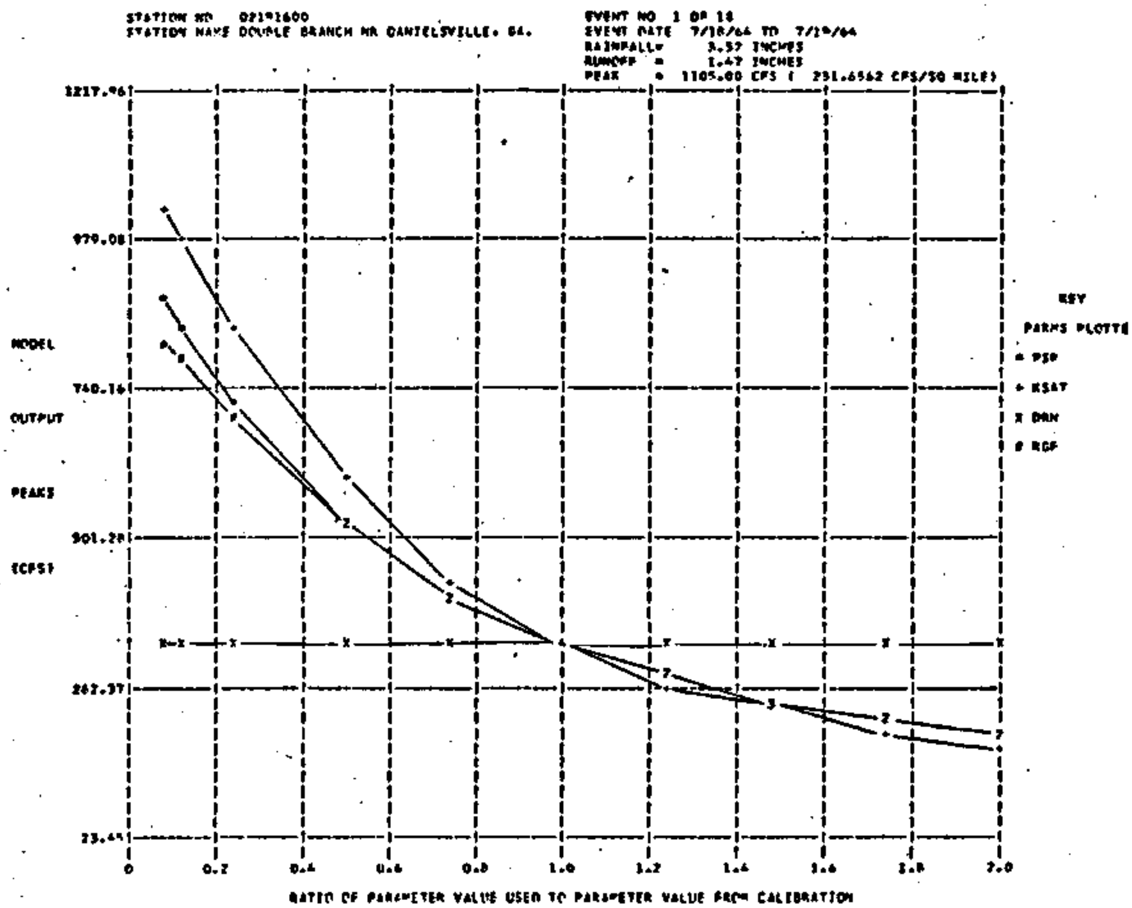

Figure C.1 Variation of the Simulated Peak Discharge for a Storm Event as a Parameter varies about its Calibrated Value.

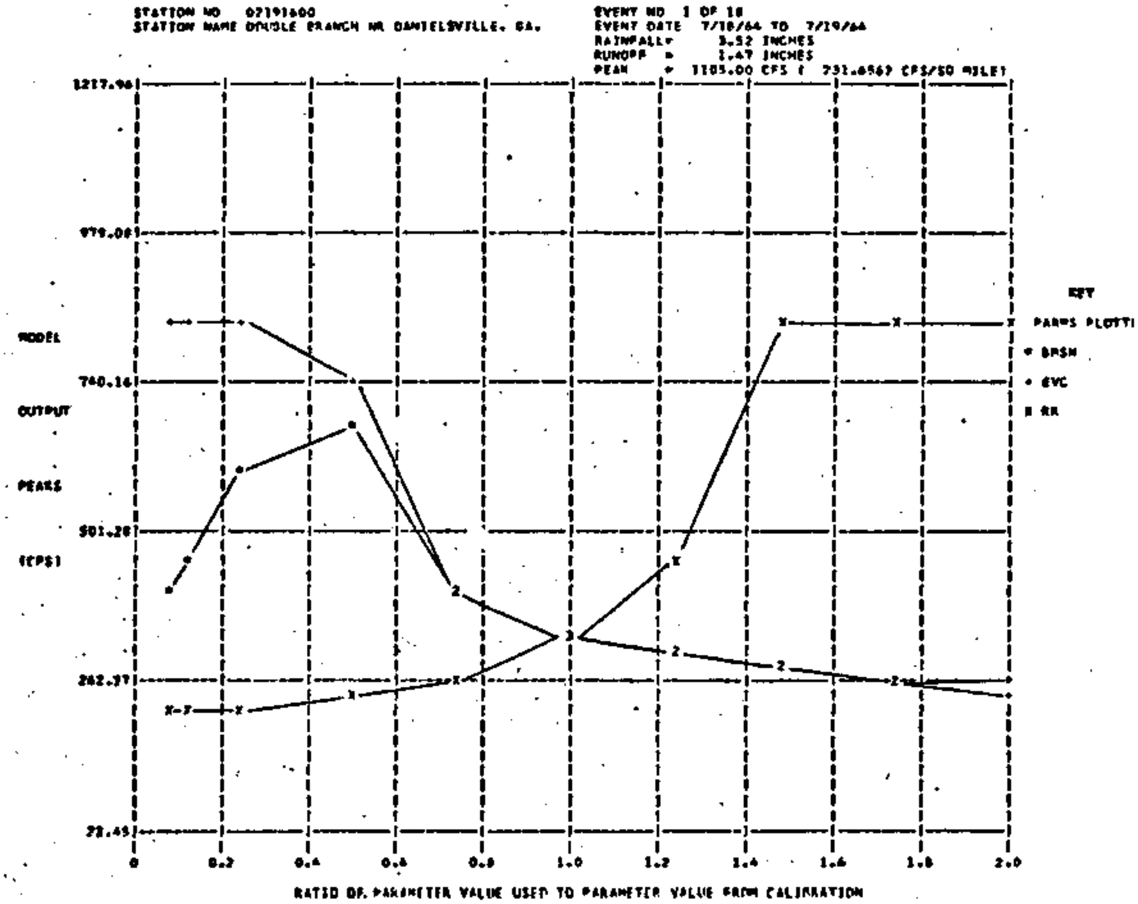

Figure C.2 Variation of the Simulated Peak Discharge for a Storm Event as a Parameter varies about its Calibrated Value.

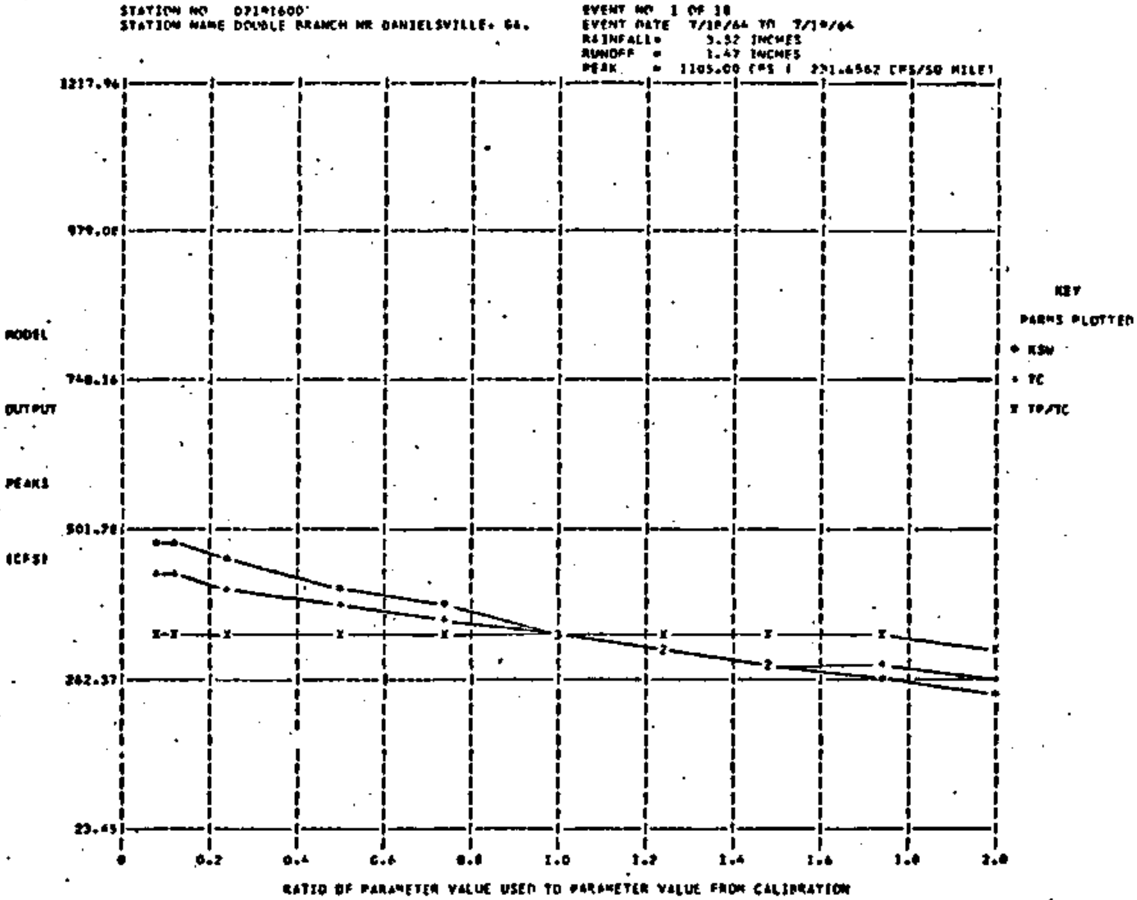

Figure C.3 Variation of the Simulated Peak Discharge for a Storm Event as a Parameter varies about its Calibrated Value.

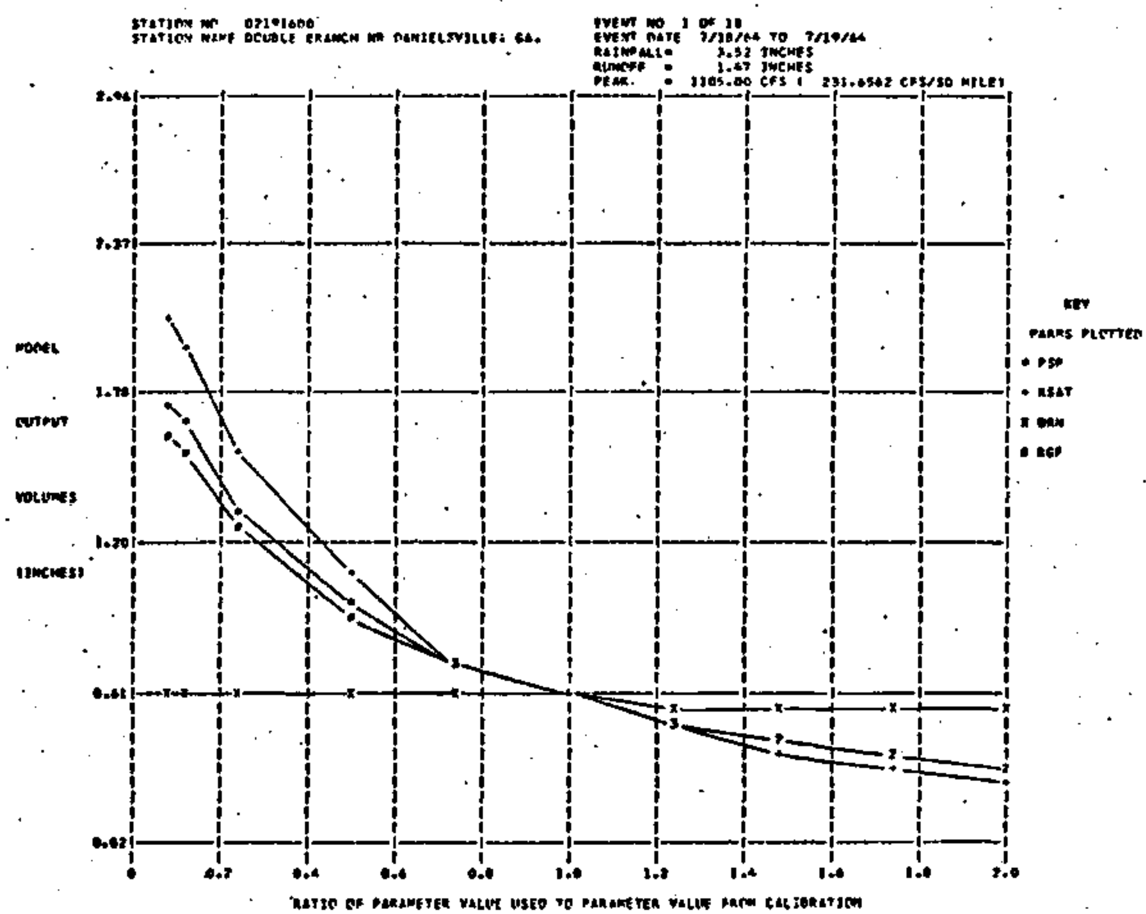

Figure C.4 Variation of the Simulated Runoff Volume for a Storm Event as a Parameter varies about its Calibrated Value.

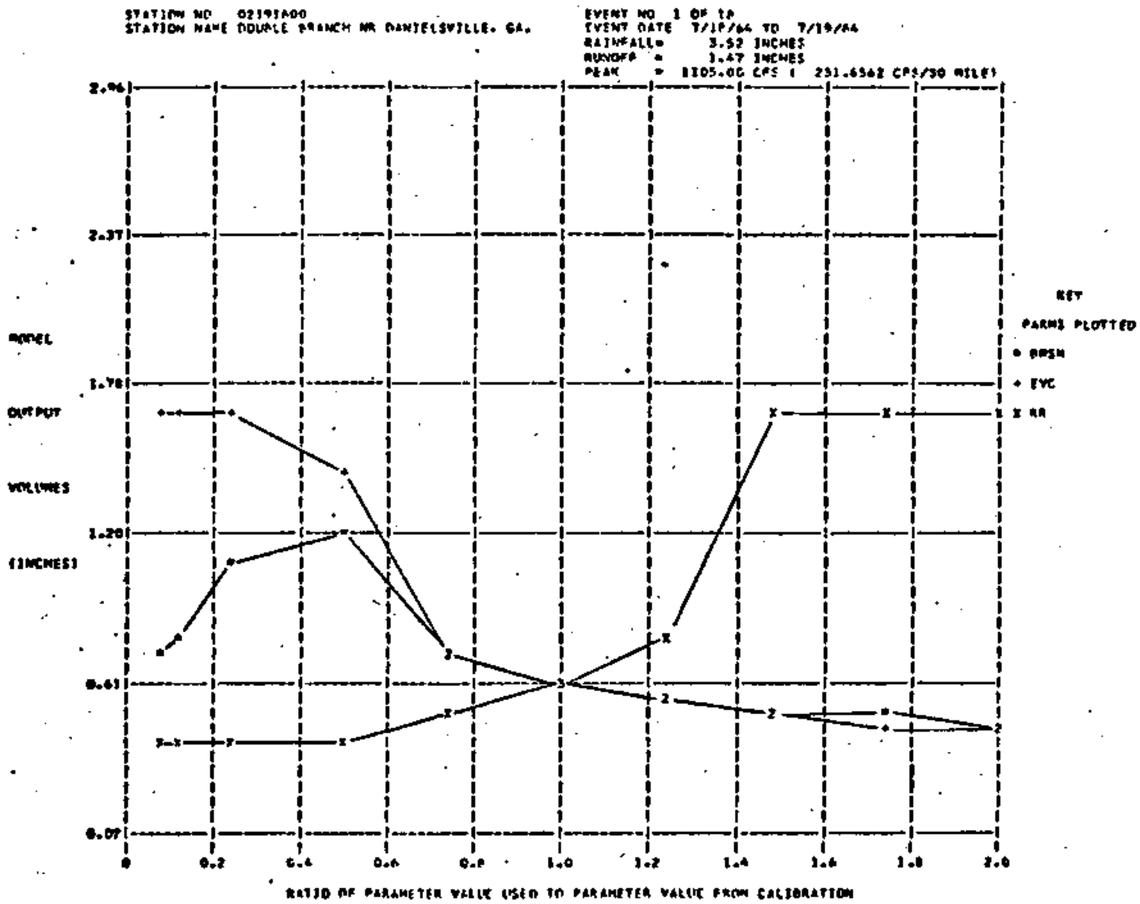

Figure C.5 Variation of the Simulated Runoff Volume for a Storm Event as a Parameter varies about its Calibrated Value.

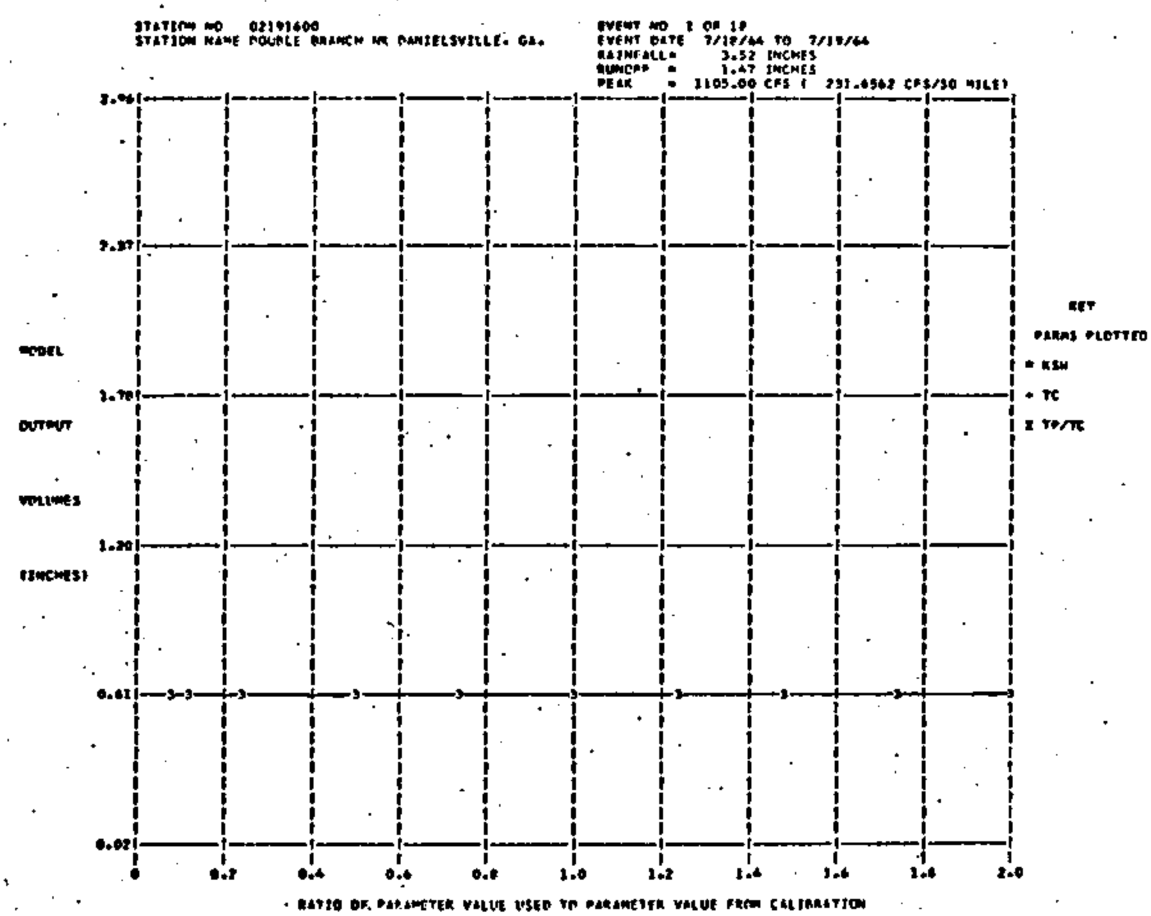

Figure C.6 Variation of the Simulated Runoff Volume for a Storm Event as a Parameter varies about its Calibrated Value.

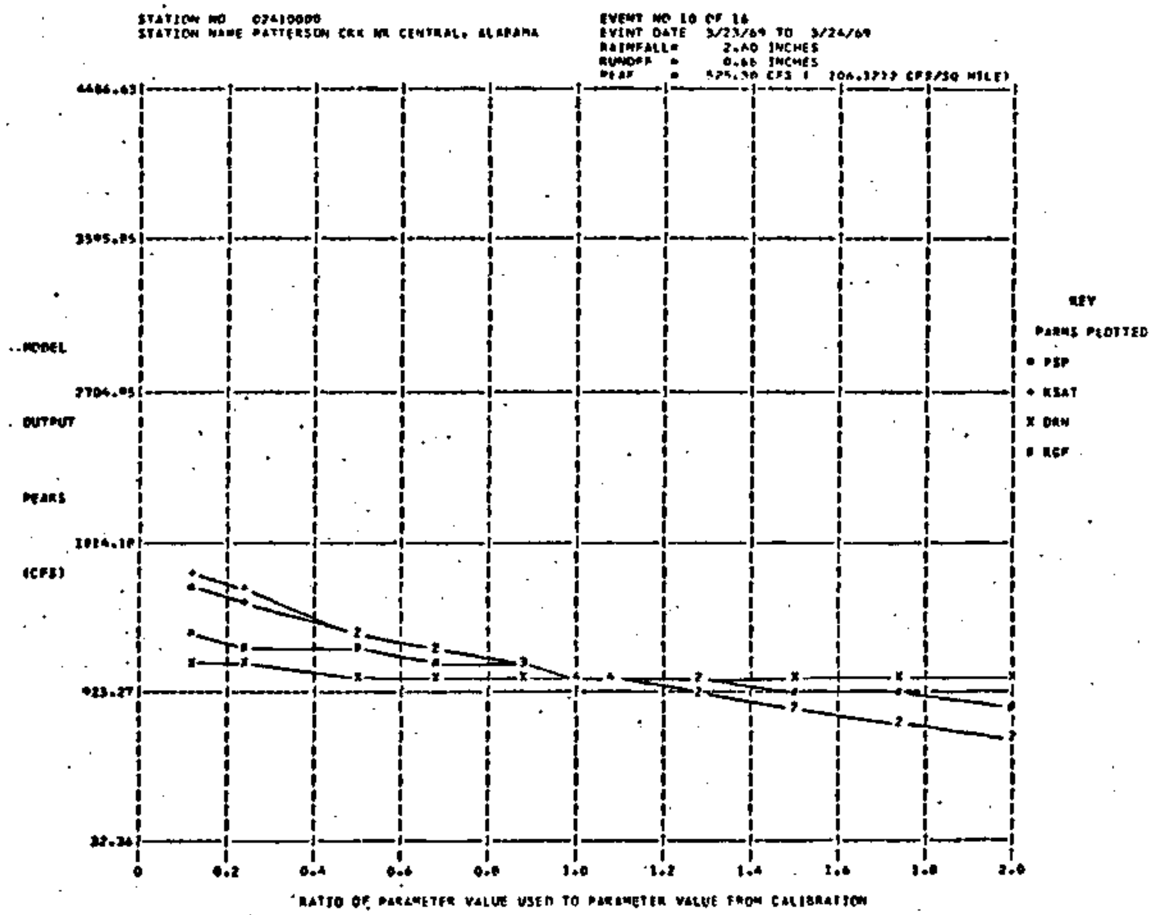

Figure C.7 Variation of the Simulated Peak Discharge for a Storm Event as a Parameter varies about its Calibrated Value.

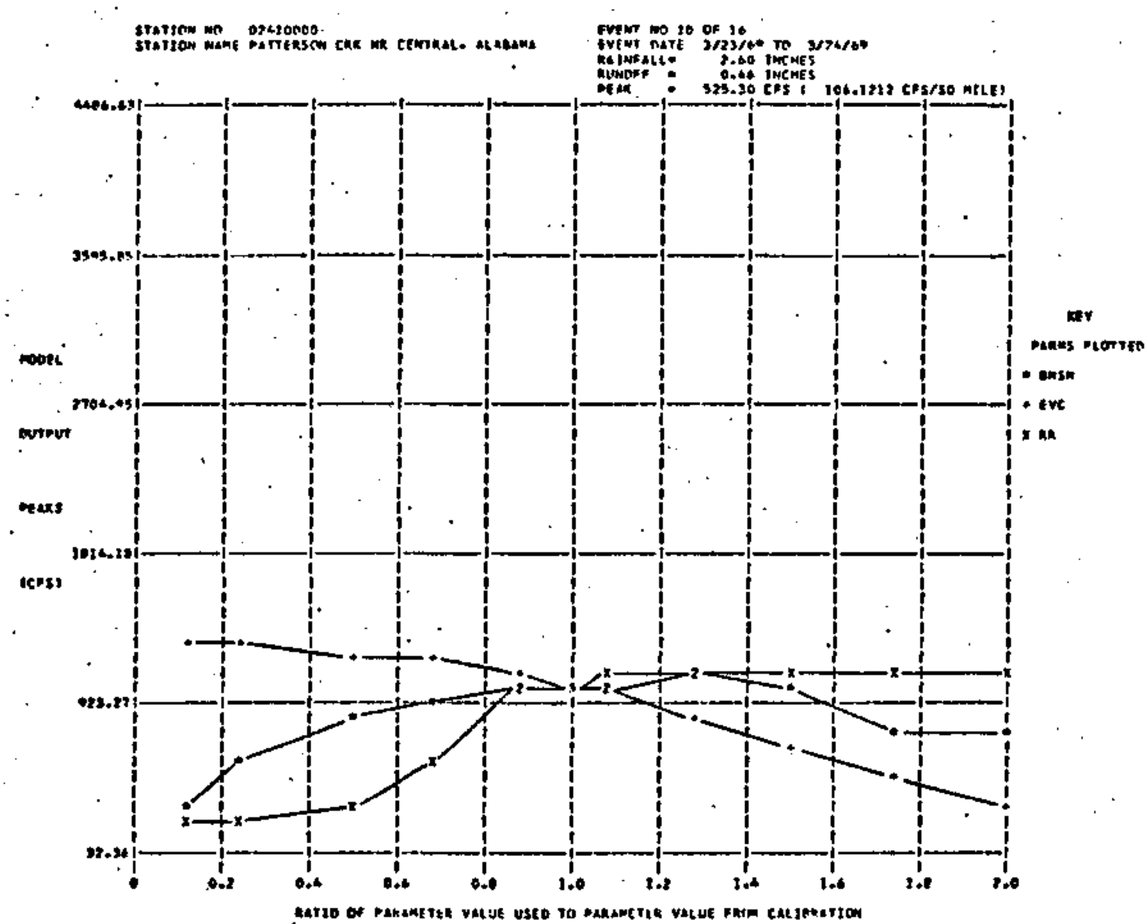

Figure C.8 Variation of the Simulated Peak Discharge for a Storm Event as a Parameter varies about its Calibrated Value.

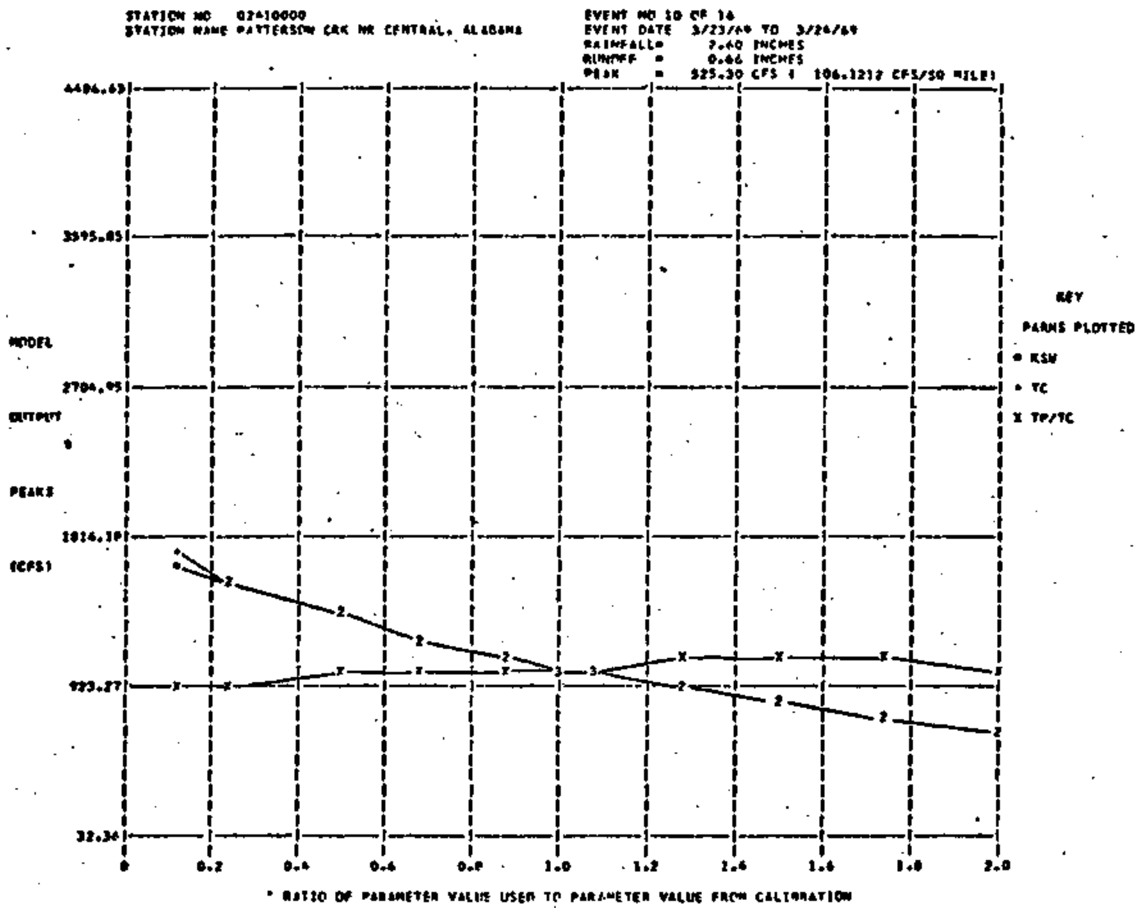

Figure C.9 Variation of the Simulated Peak Discharge for a Storm Event as a Parameter varies about its Calibrated Value.

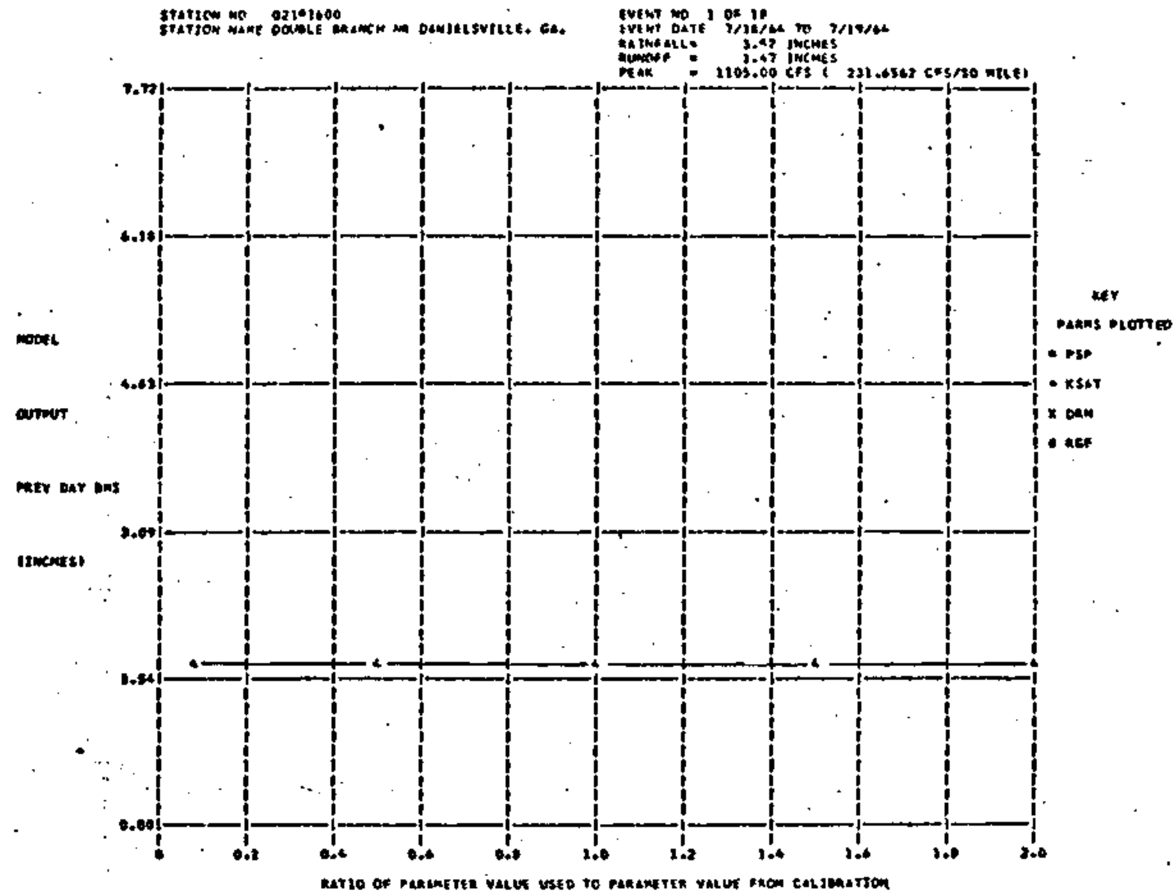

Figure C.10 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

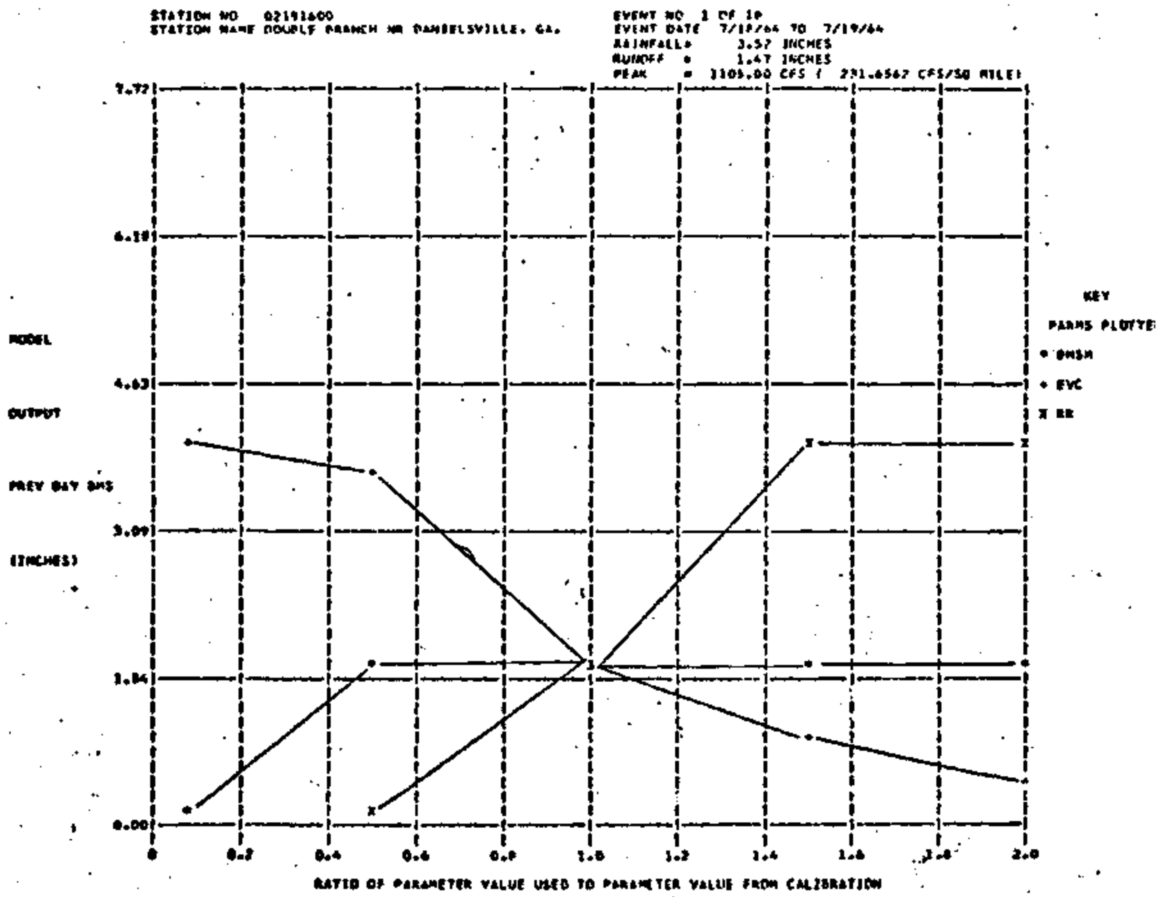

Figure C.11 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

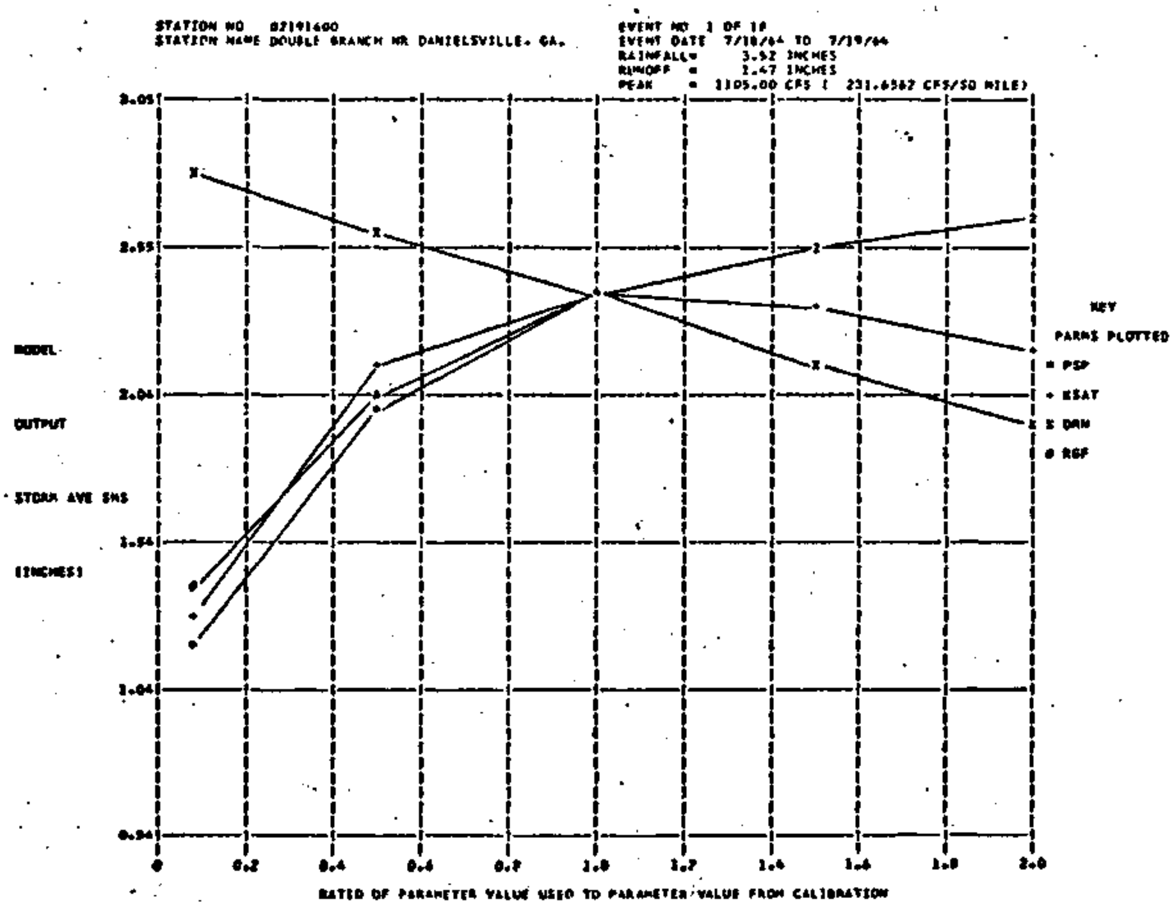

Figure C.12 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

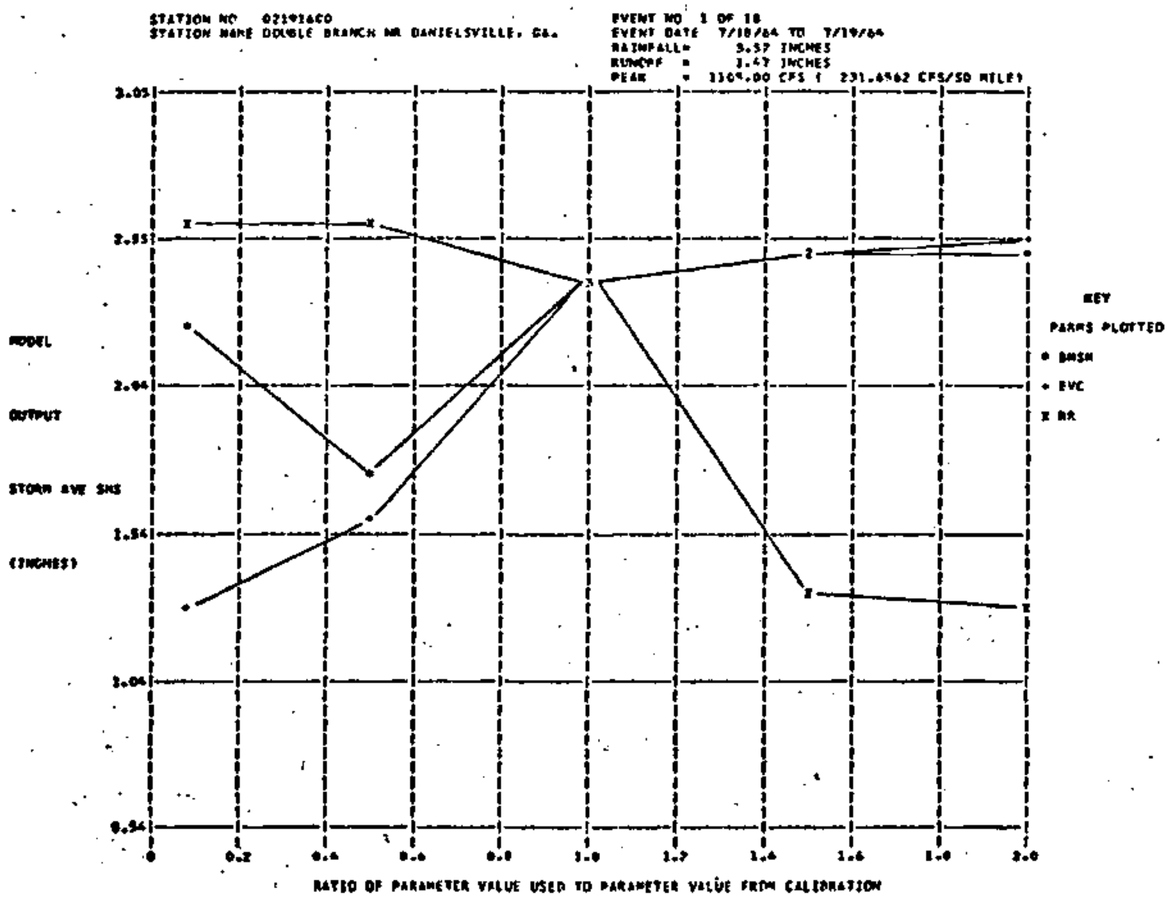

Figure C.13 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

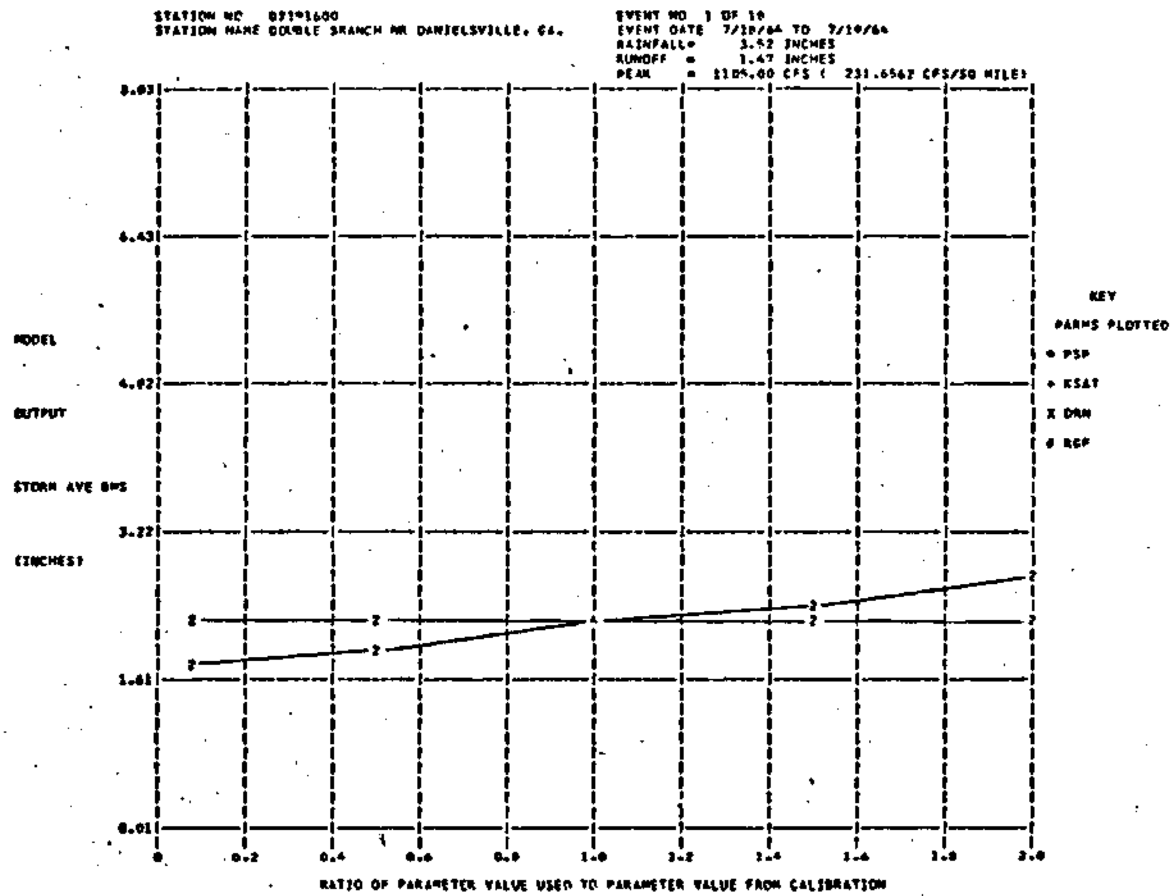

Figure C.14 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

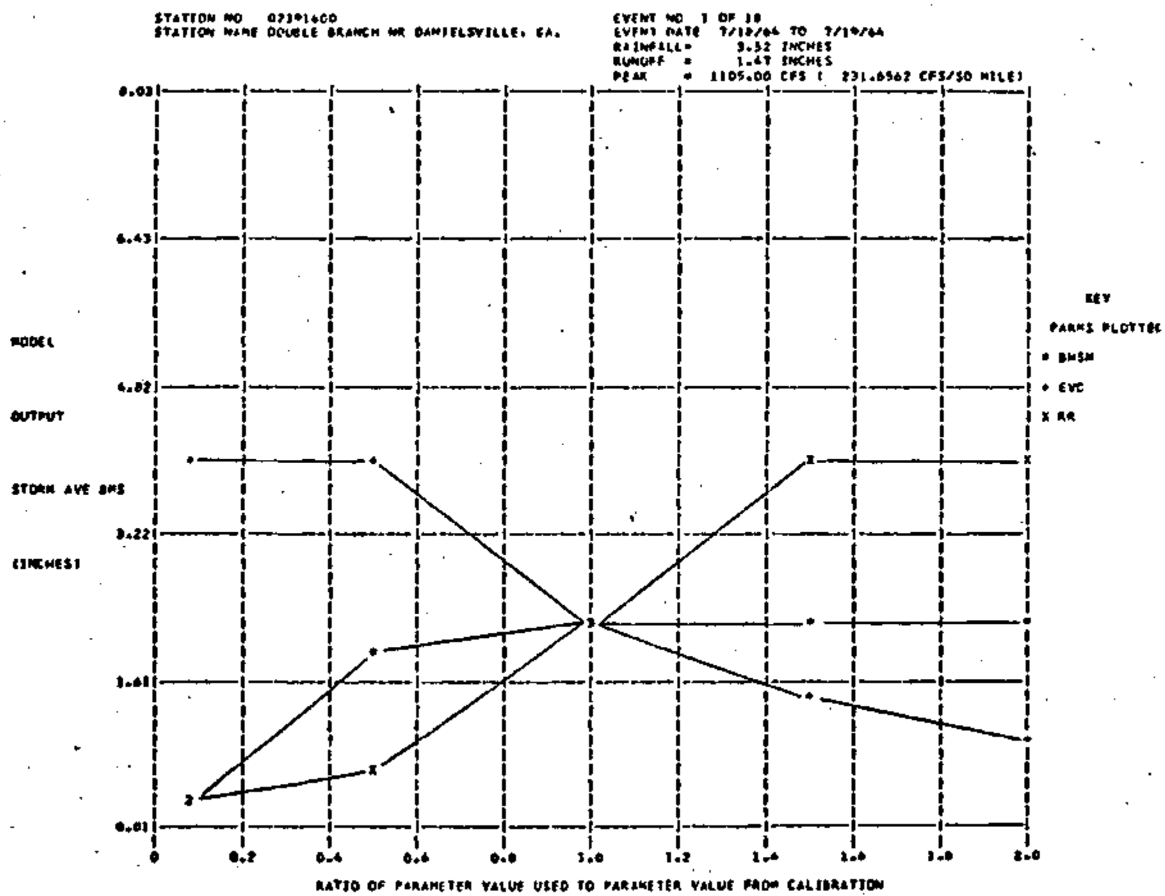

Figure C.15 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

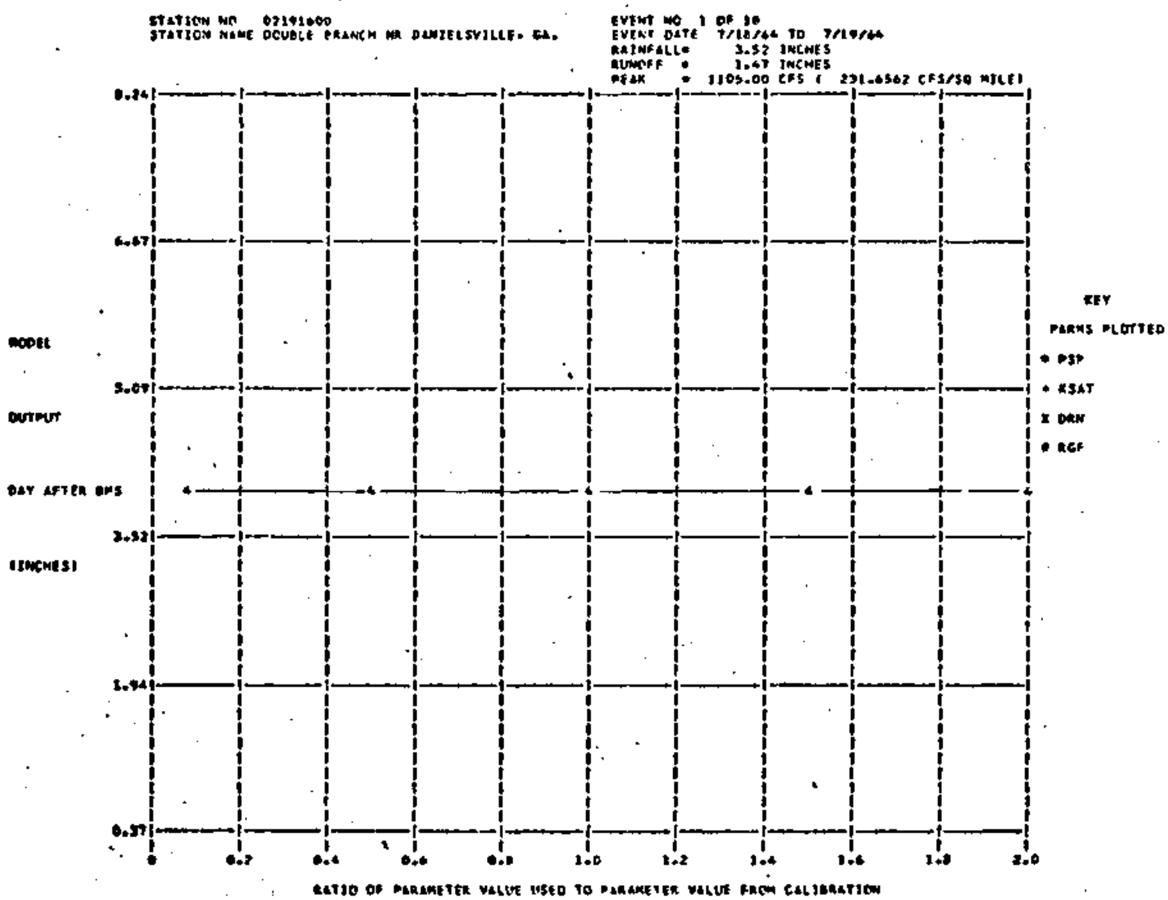

Figure C.16 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

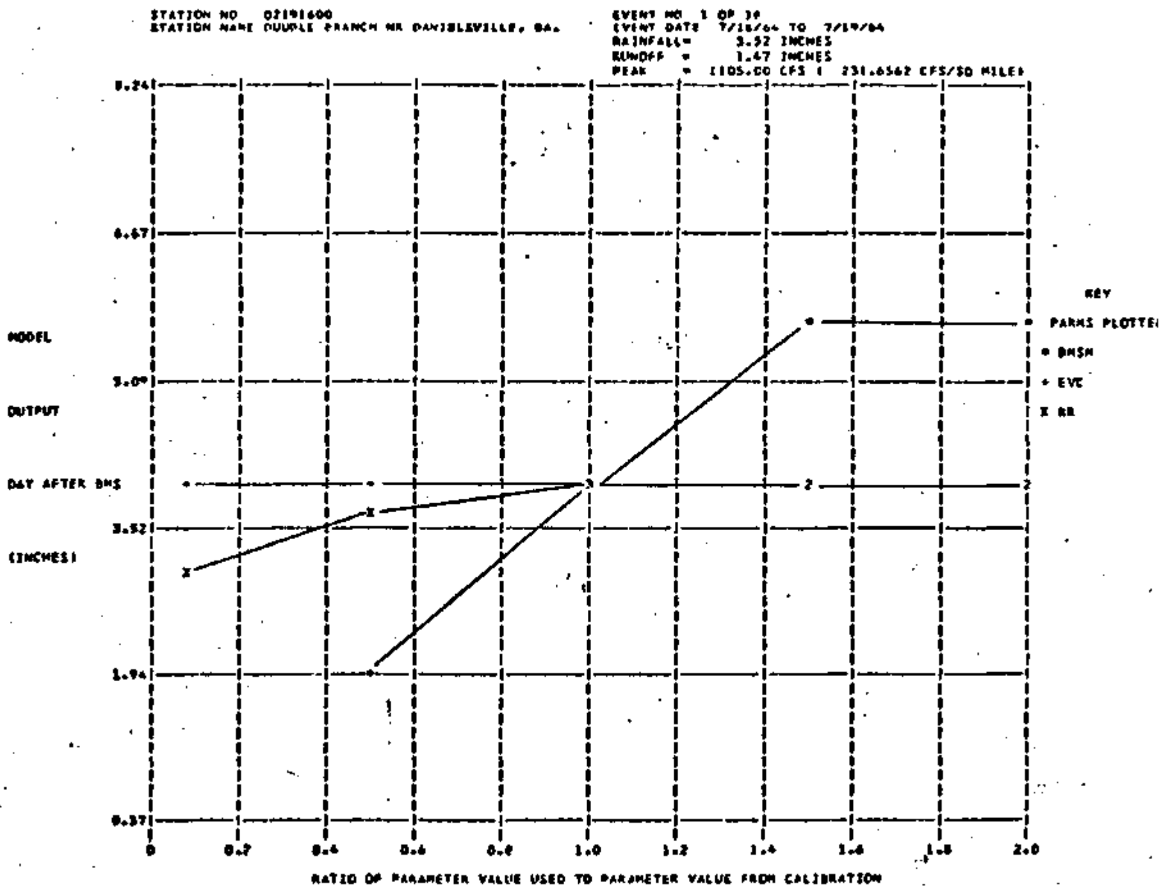

Figure C.17 Variation of the Simulated Moisture Storage Values for a Storm Event as a Parameter varies about its Calibrated Value.

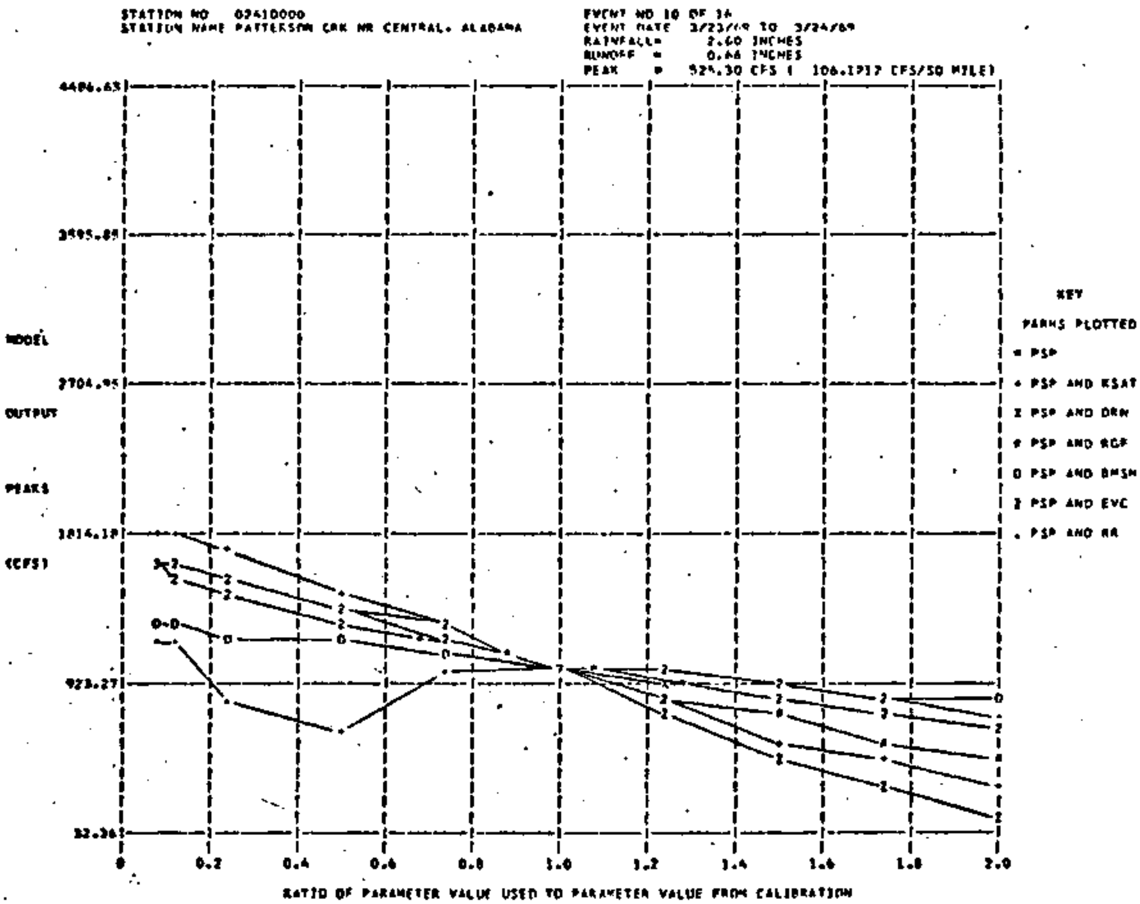

Figure C.18 Variation of the Simulated Peak Discharge for a Storm Event as PSP or PSP and another Volume Parameter vary about their Calibrated Values.

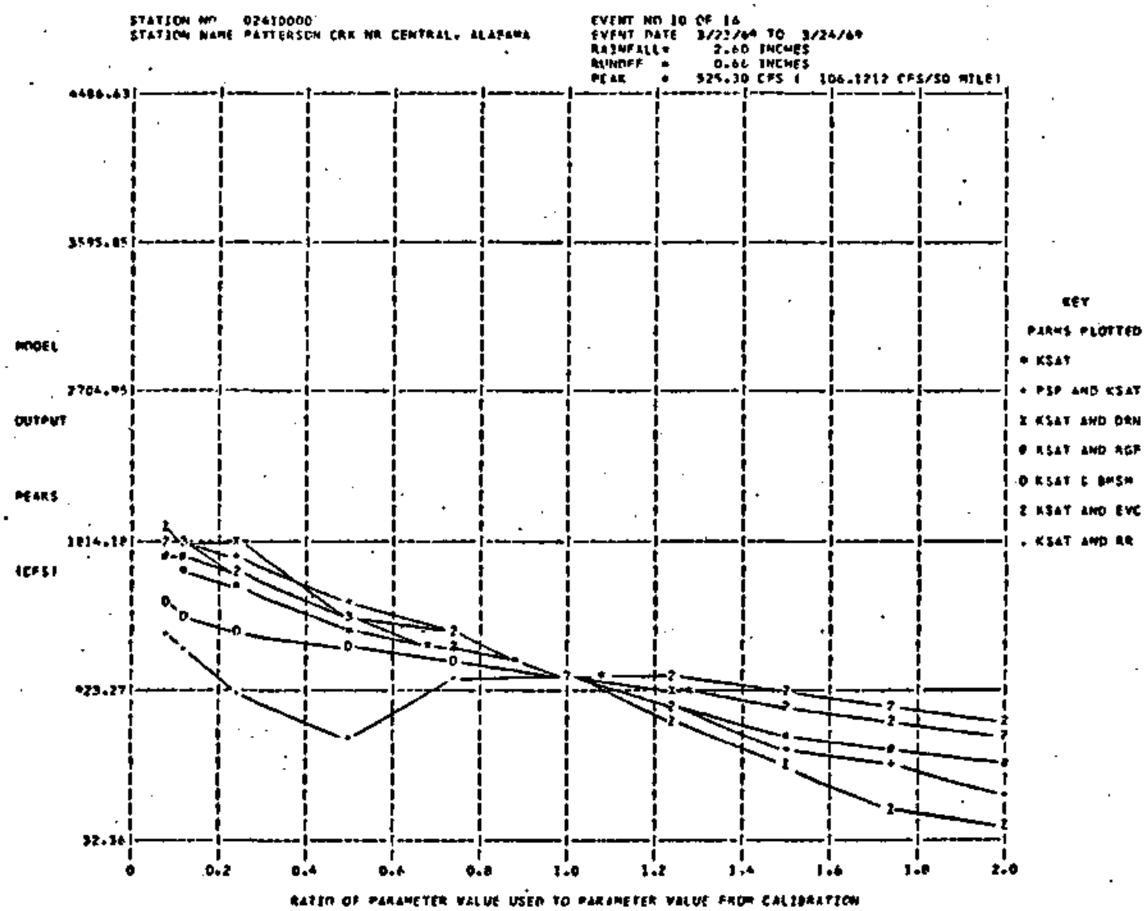

Figure C.19 Variation of the Simulated Peak Discharge for a Storm Event as KSAT or KSAT and another Volume Parameter vary about their Calibrated Values.

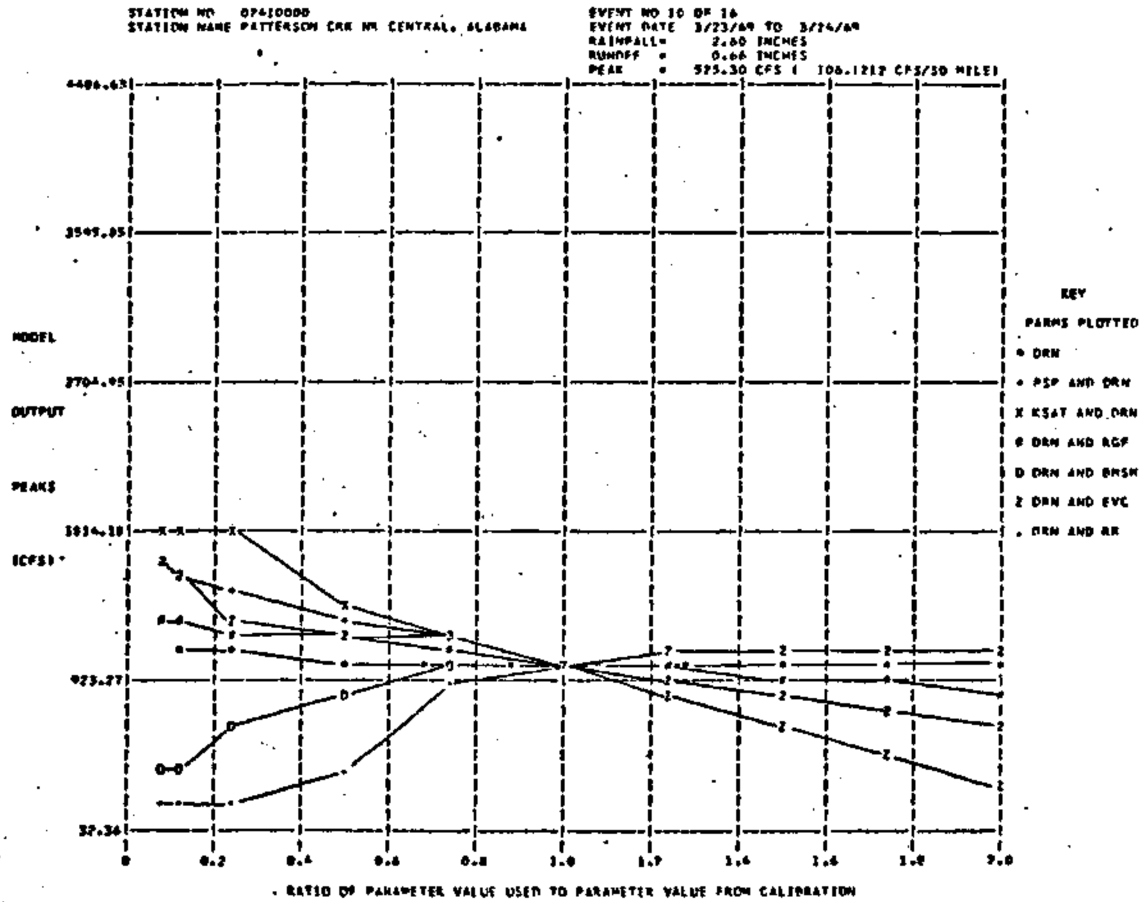

Figure C.20 Variation of the Simulated Peak Discharge for a Storm Event as DRN or DRN and another Volume Parameter vary about their Calibrated Values.

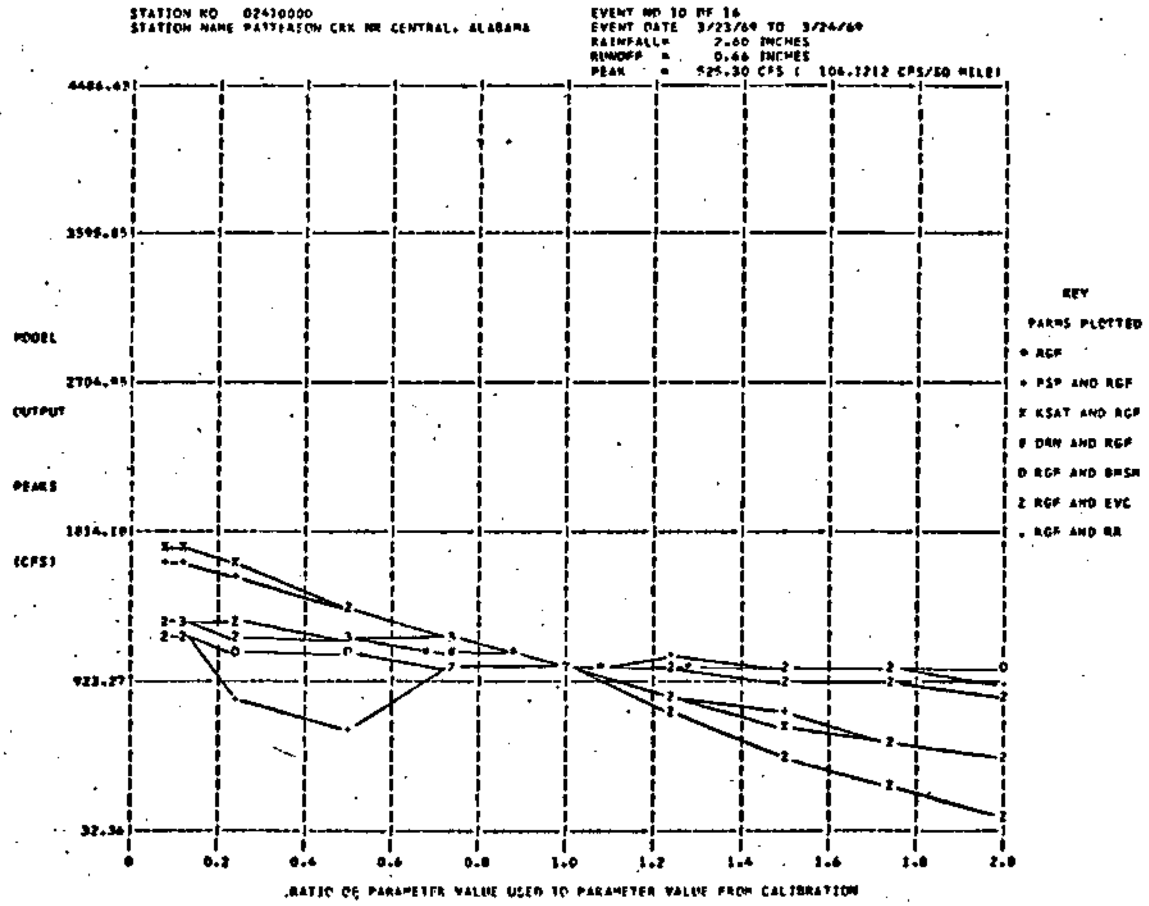

Figure C.21 Variation of the Simulated Peak Discharge for a Storm Event as RGF or RGF and another Volume Parameter vary about their Calibrated Values.

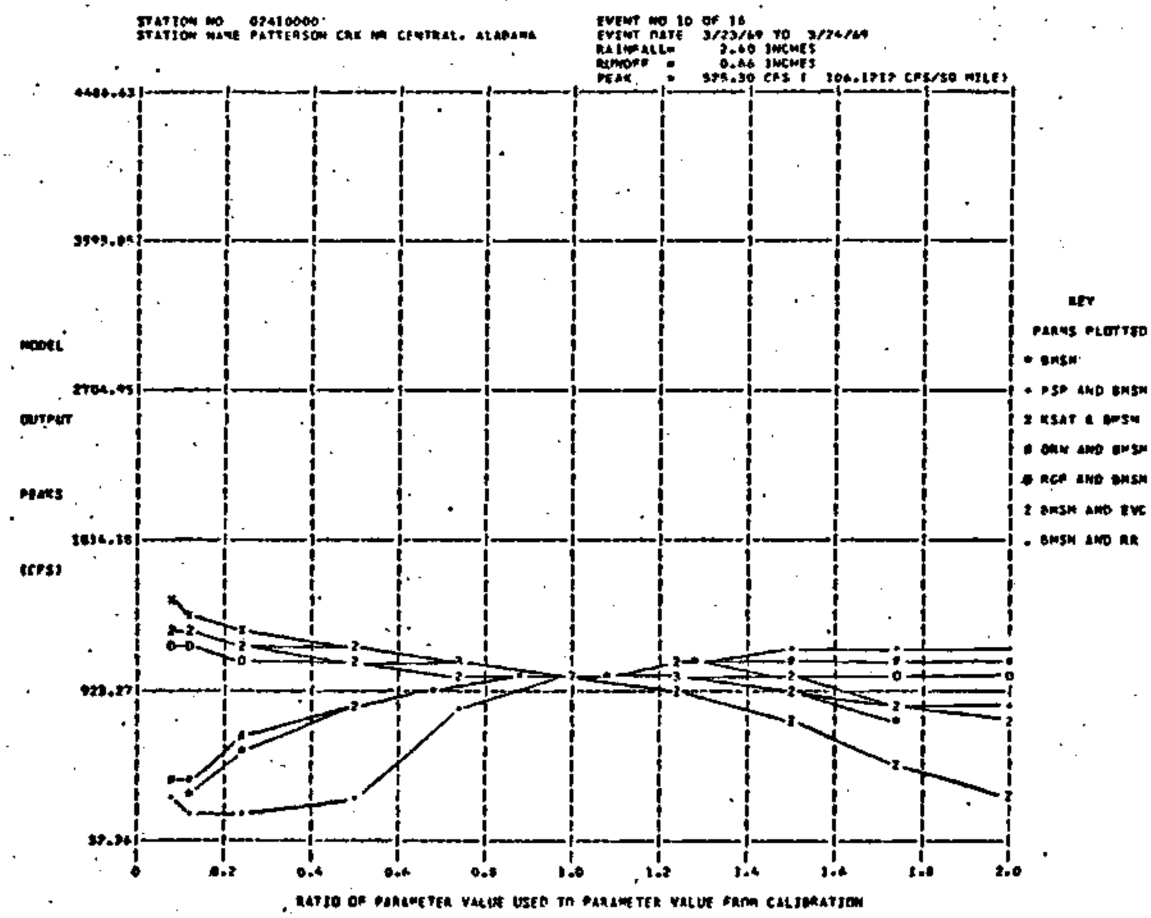

Figure C.22 Variation of the Simulated Peak Discharge for a Storm Event as BMSM or BMSM and another Volume Parameter vary about their Calibrated Values.

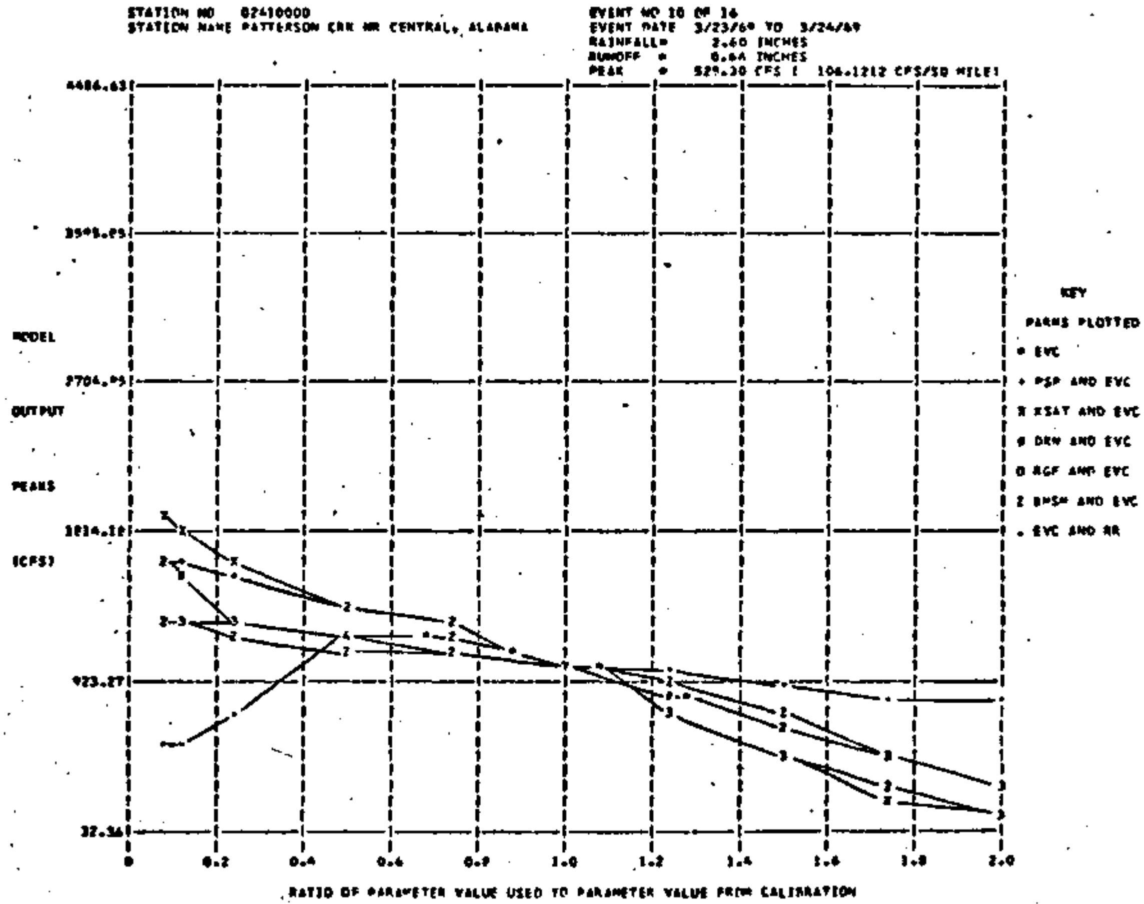

Figure C.23 Variation of the Simulated Peak Discharge for a Storm Event as EVC or EVC and another Volume Parameter vary about their Calibrated Values.

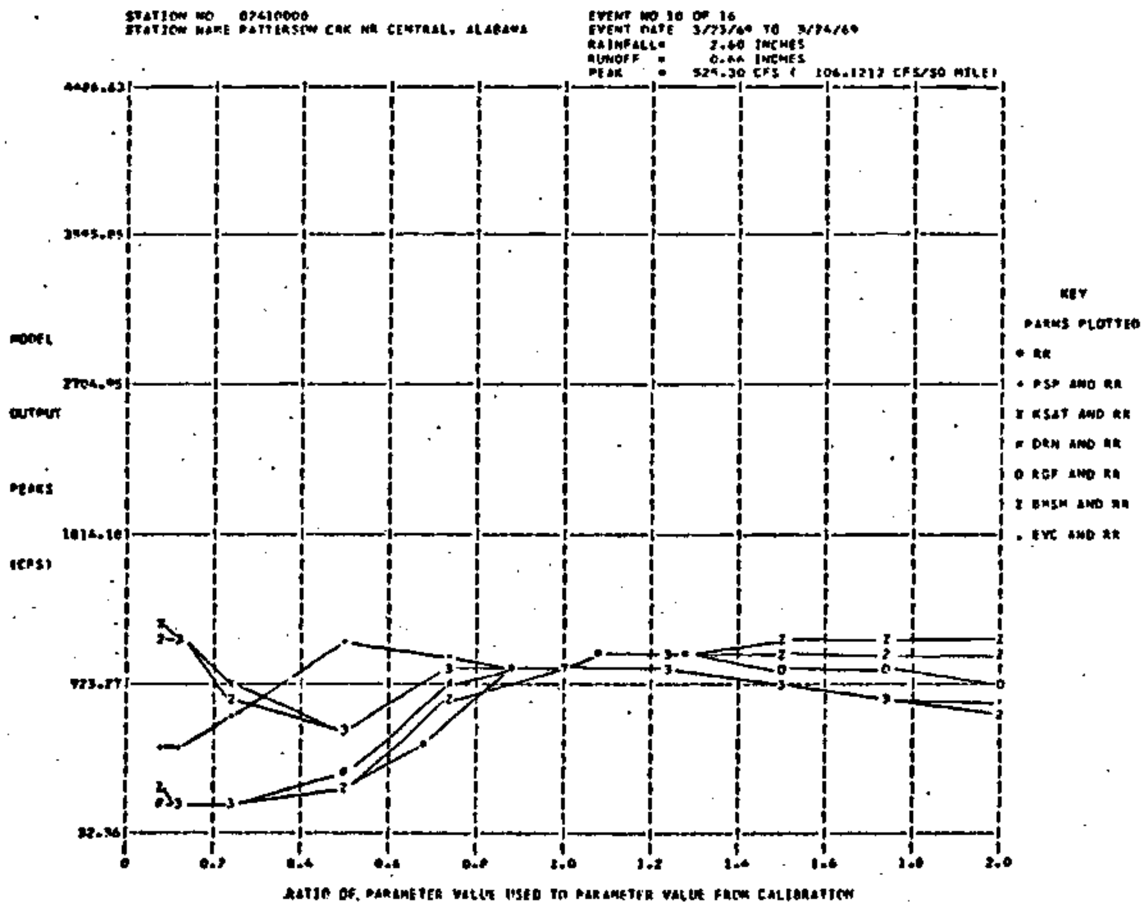

Figure C.24 Variation of the Simulated Peak Discharge for a Storm Event as RR or RR and another Volume Parameter vary about their Calibrated Values.

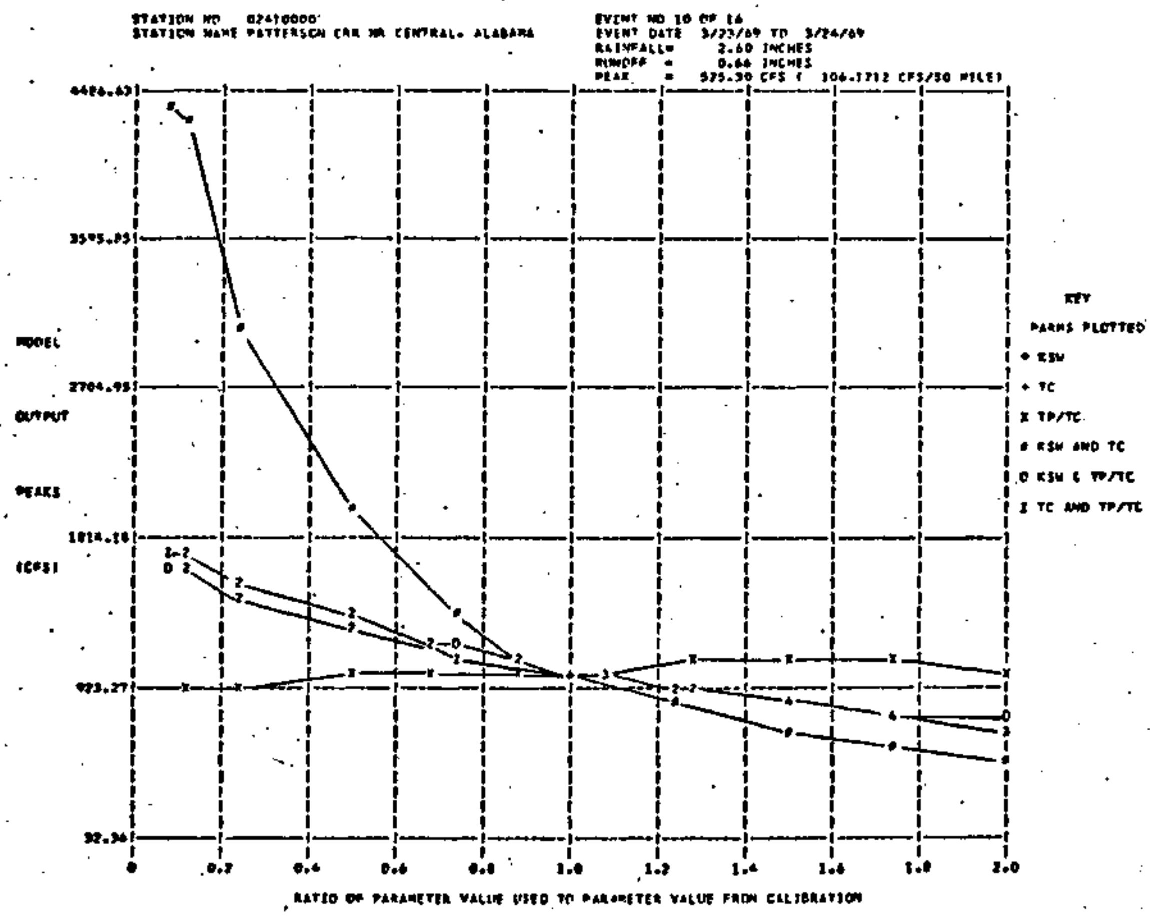

Figure C.25 Variation of the Simulated Peak Discharge for a Storm Event as KSW,TC andTP/TC vary about their Calibrated Values either individually or in pairs.

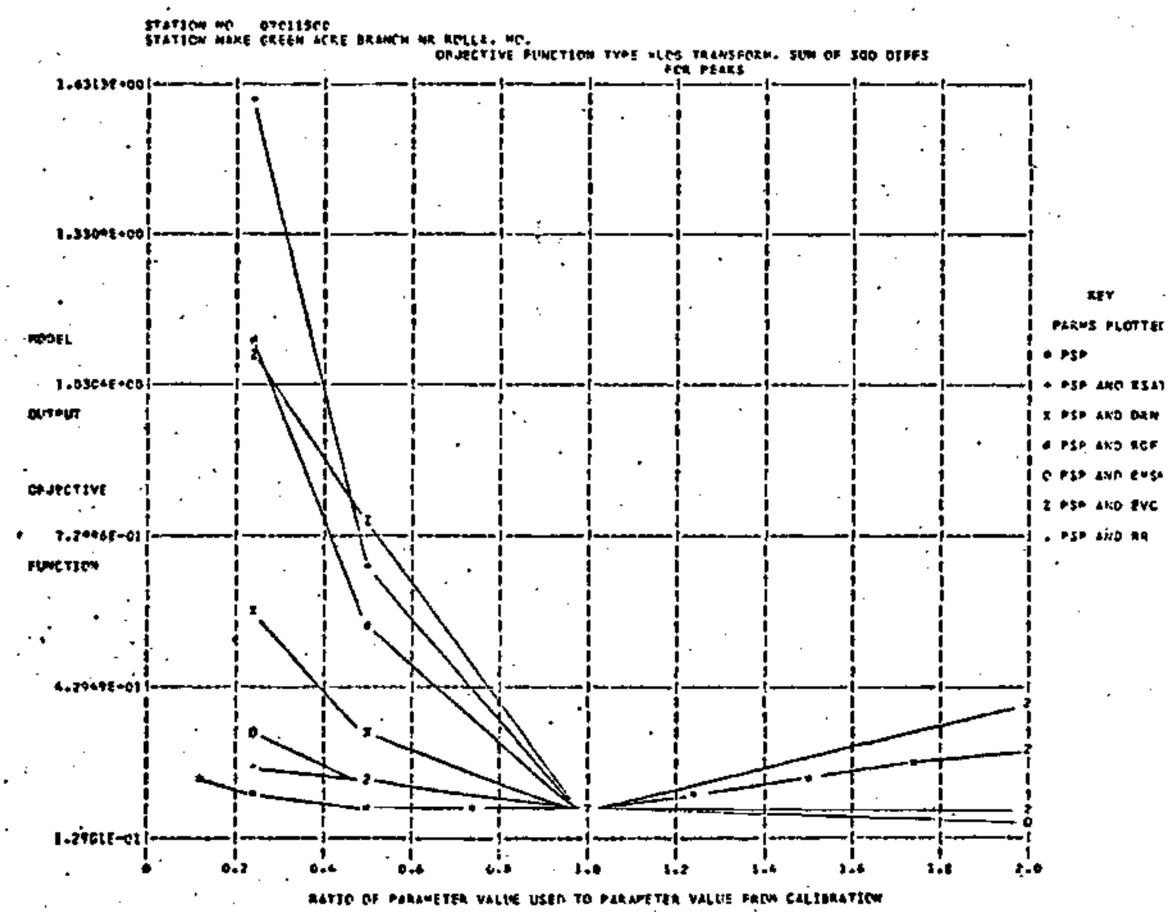

Figure C.26 Variation of the Objective Function Value as PSP or PSP and another Volume Parameter vary about their Calibrated Values.

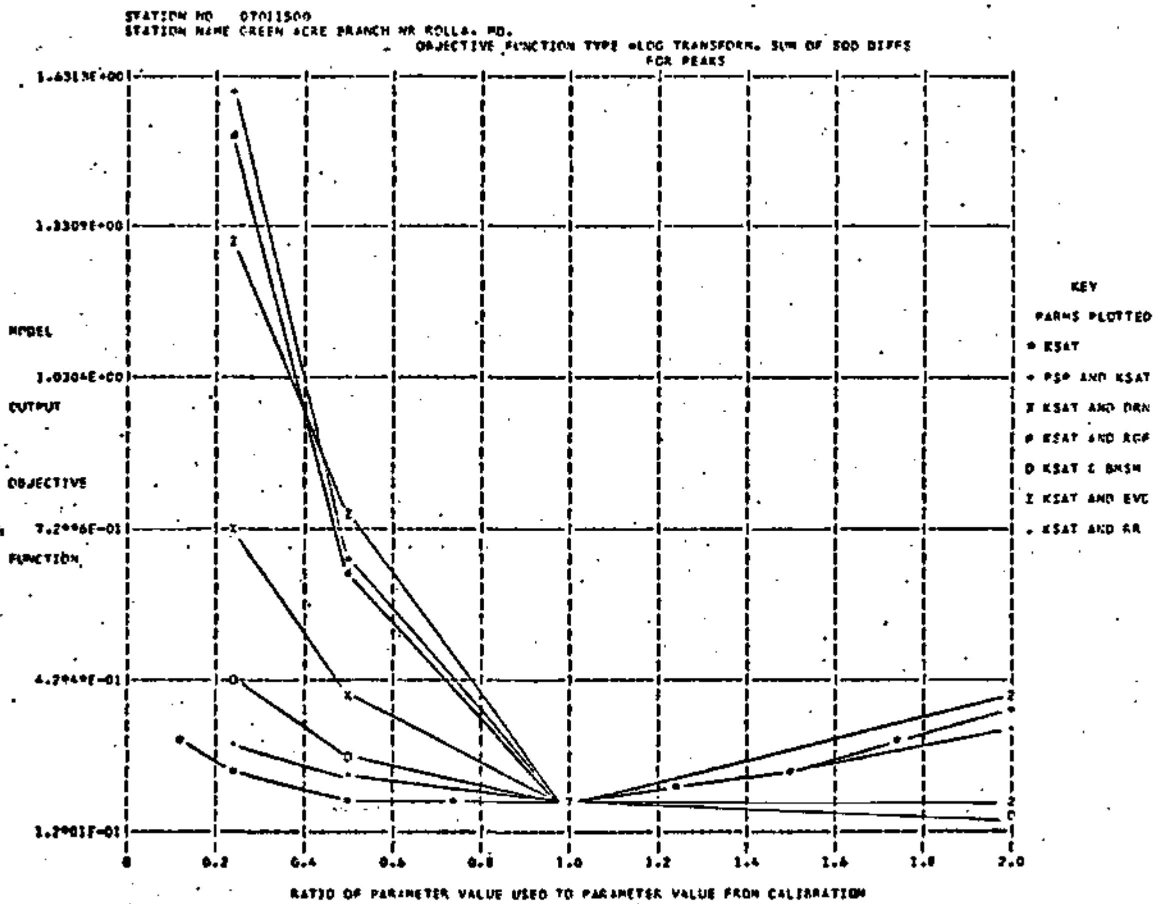

Figure C.27 Variation of the Objective Function Value as KSAT or KSAT and another Volume Parameter vary about their Calibrated Values.

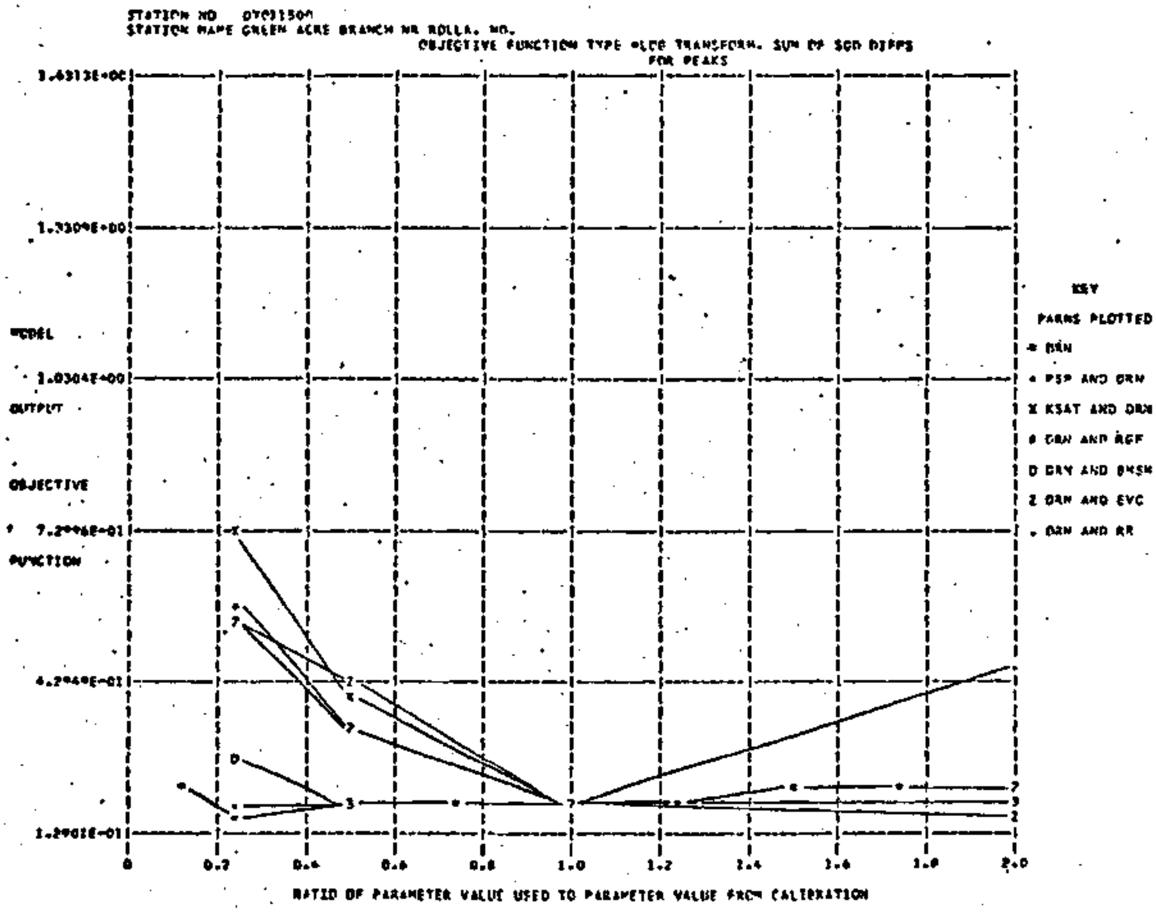

Figure C.28 Variation of the Objective Function Value as DRN or DRN and another Volume Parameter vary about their Calibrated Values.

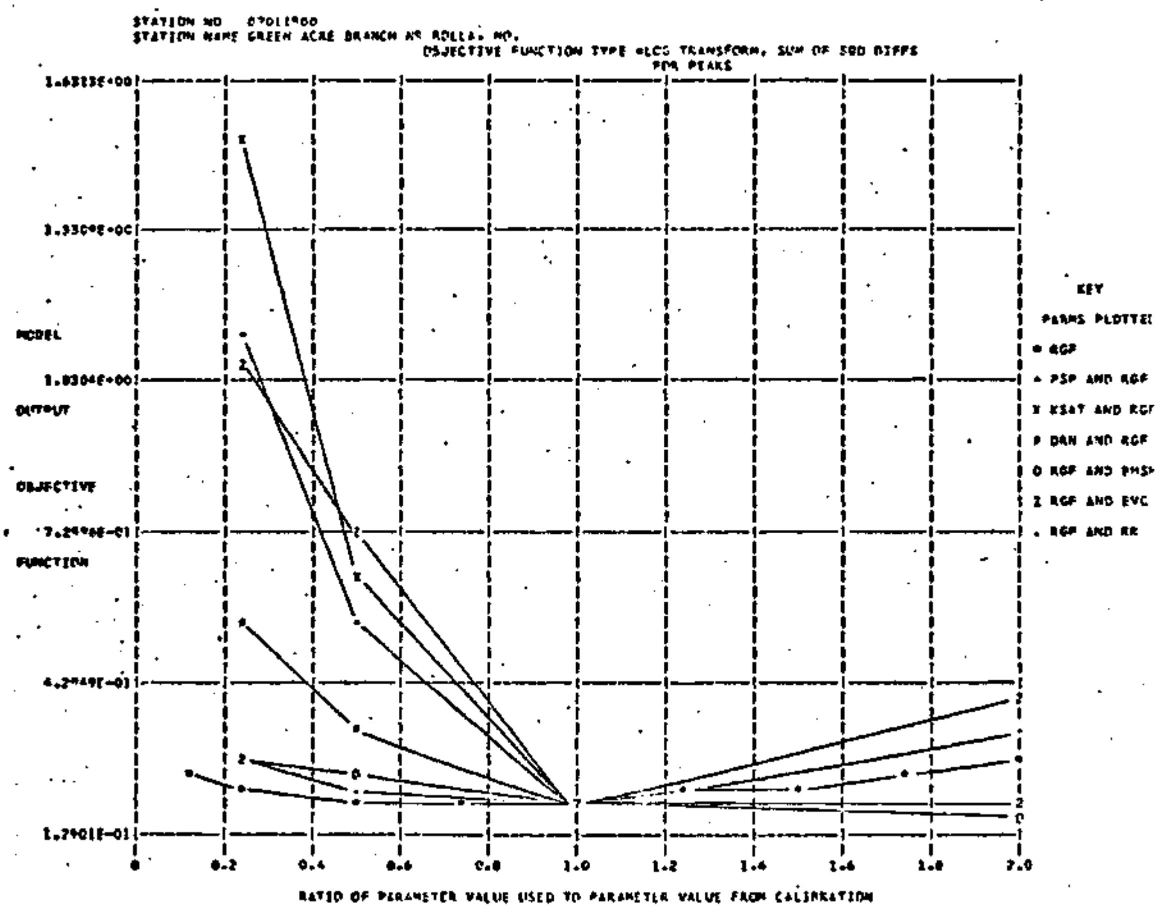

Figure C.29 Variation of the Objective Function Value as RGF or RGF and another Volume Parameter vary about their Calibrated Values.

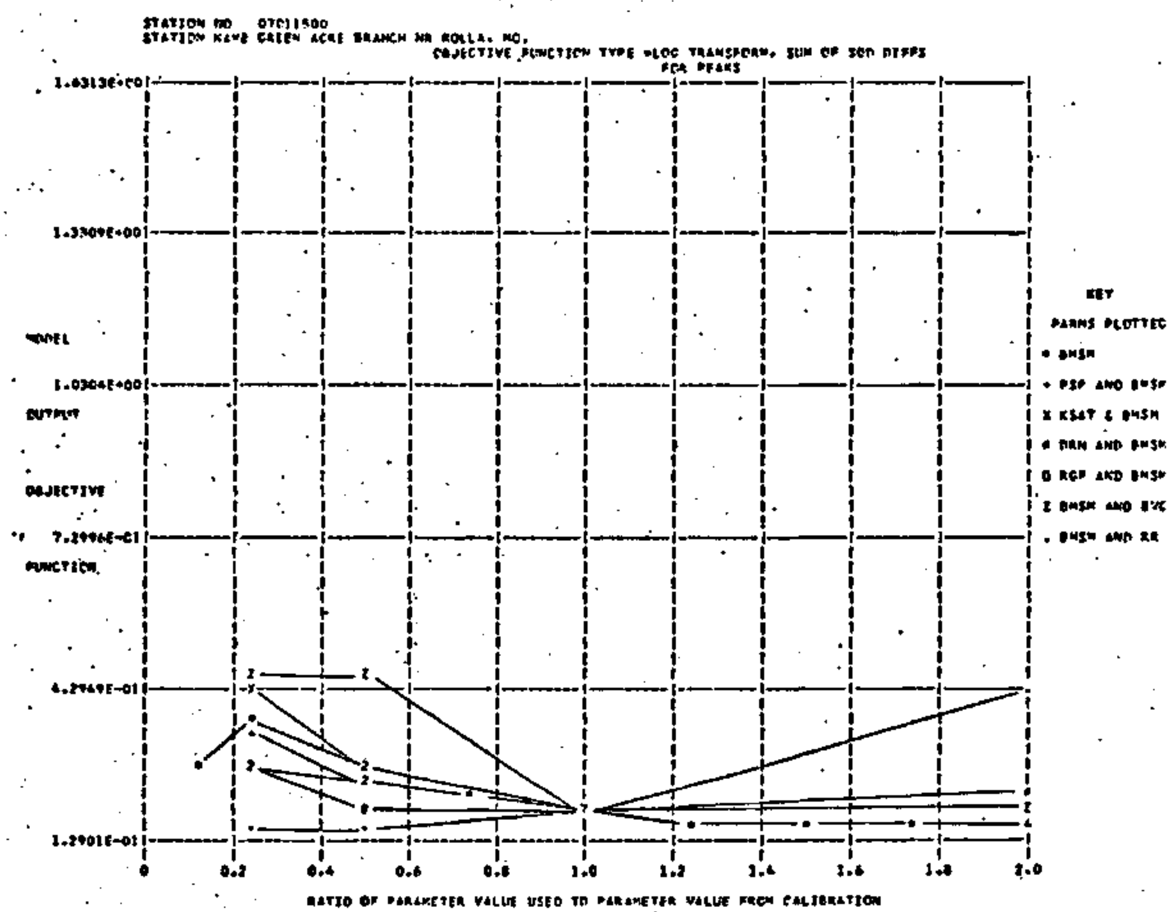

Figure C.30 Variation of the Objective Function Value as BMSM or BMSM and another Volume Parameter vary about their Calibrated Values.

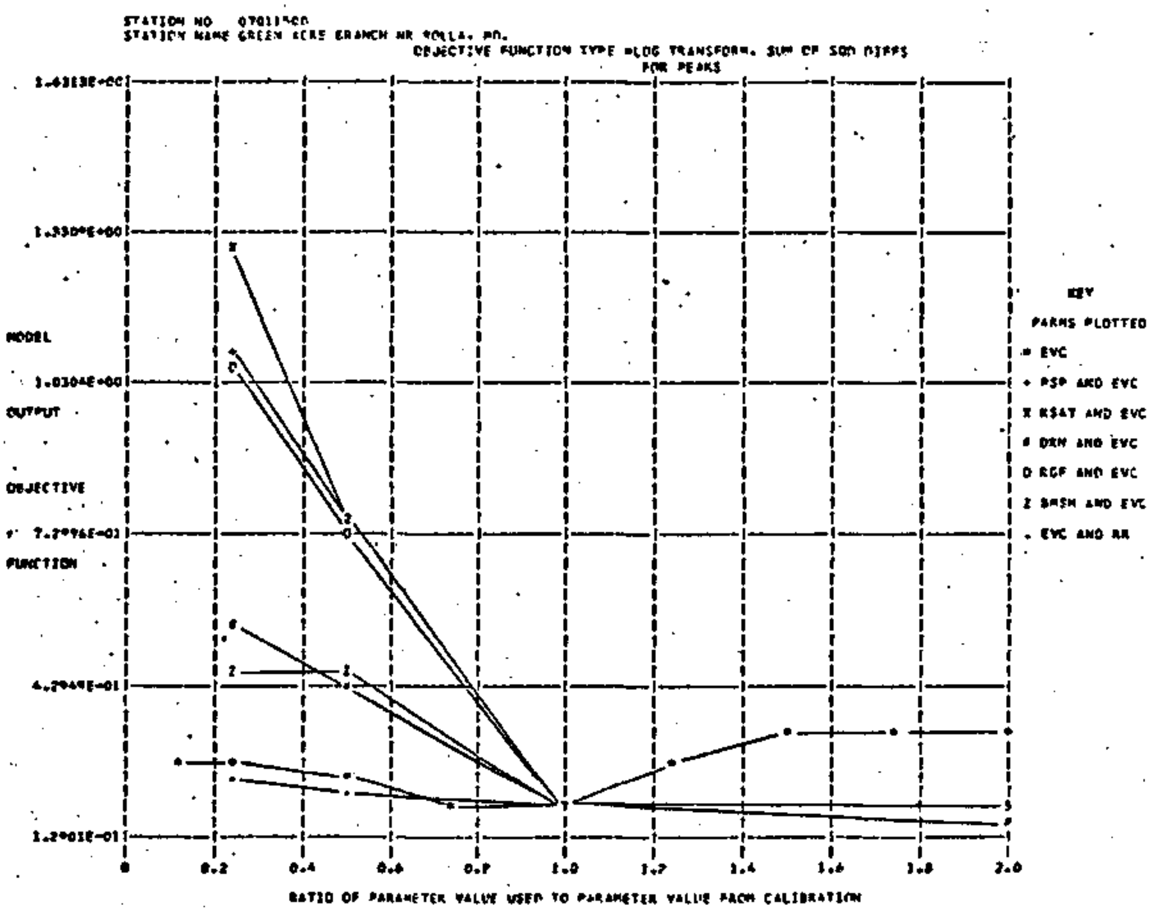

Figure C.31 Variation of the Objective Function Value as EVC or EVC and another Volume Parameter vary about their Calibrated Values.

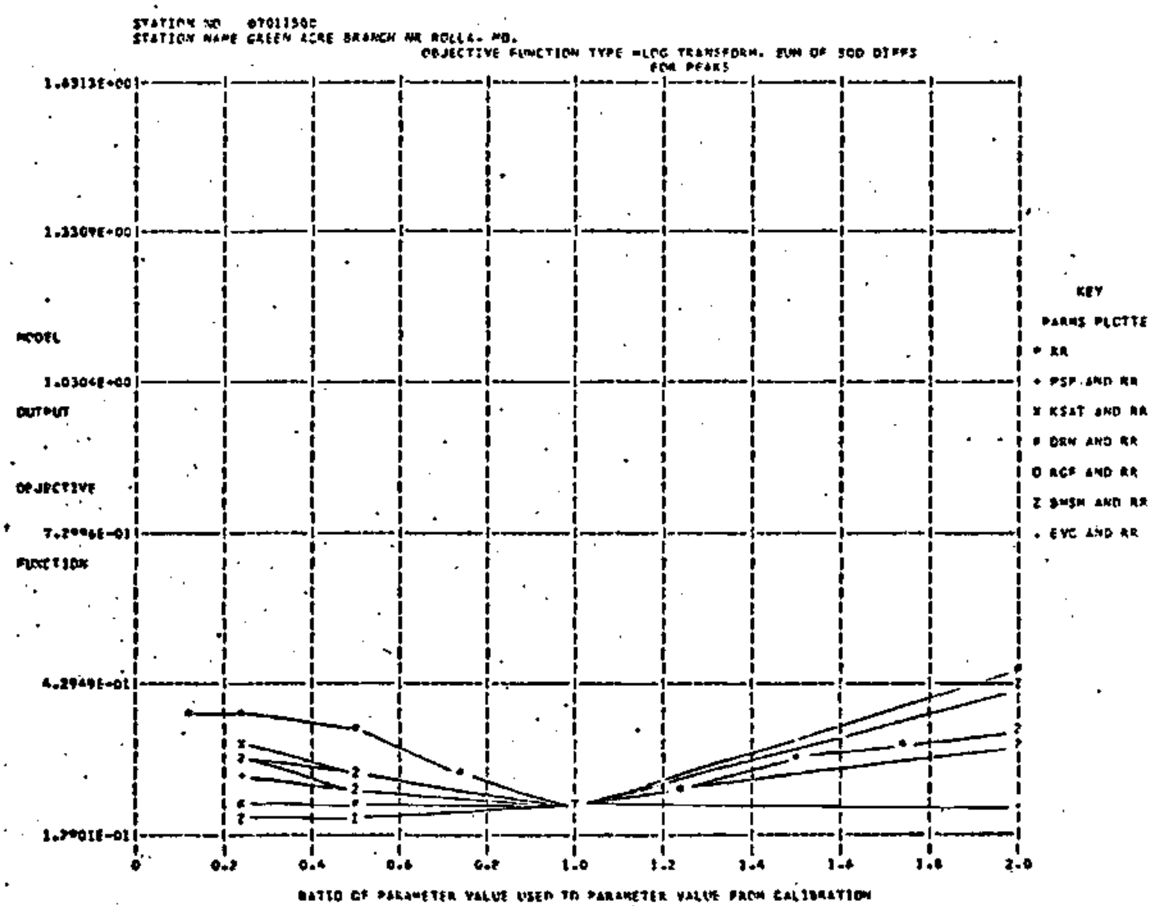

Figure C.32 Variation of the Objective Function Value as RR or RR and another Volume Parameter vary about their Calibrated Values.

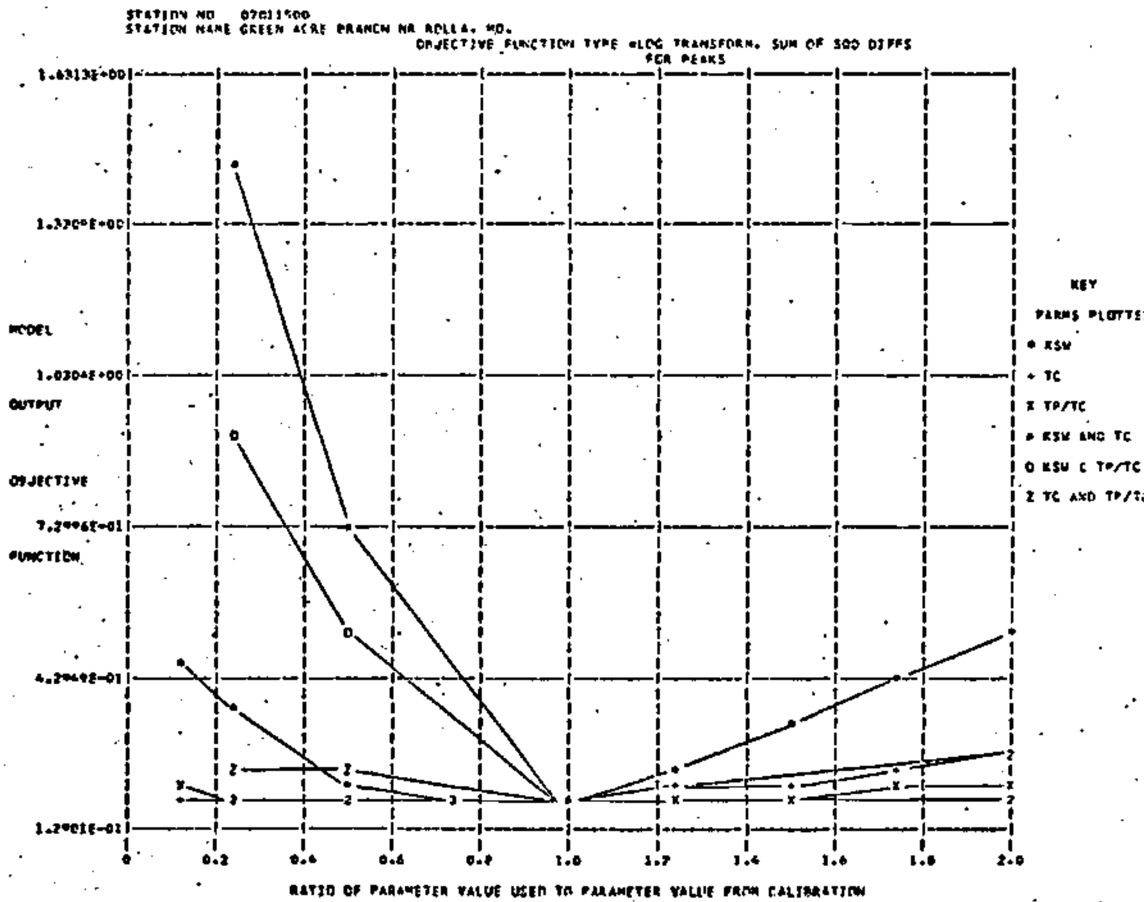

Figure C.33 Variation of the Objective Function Value as KSW, TC and TP/TC vary about their Calibrated Values either individually or in pairs.

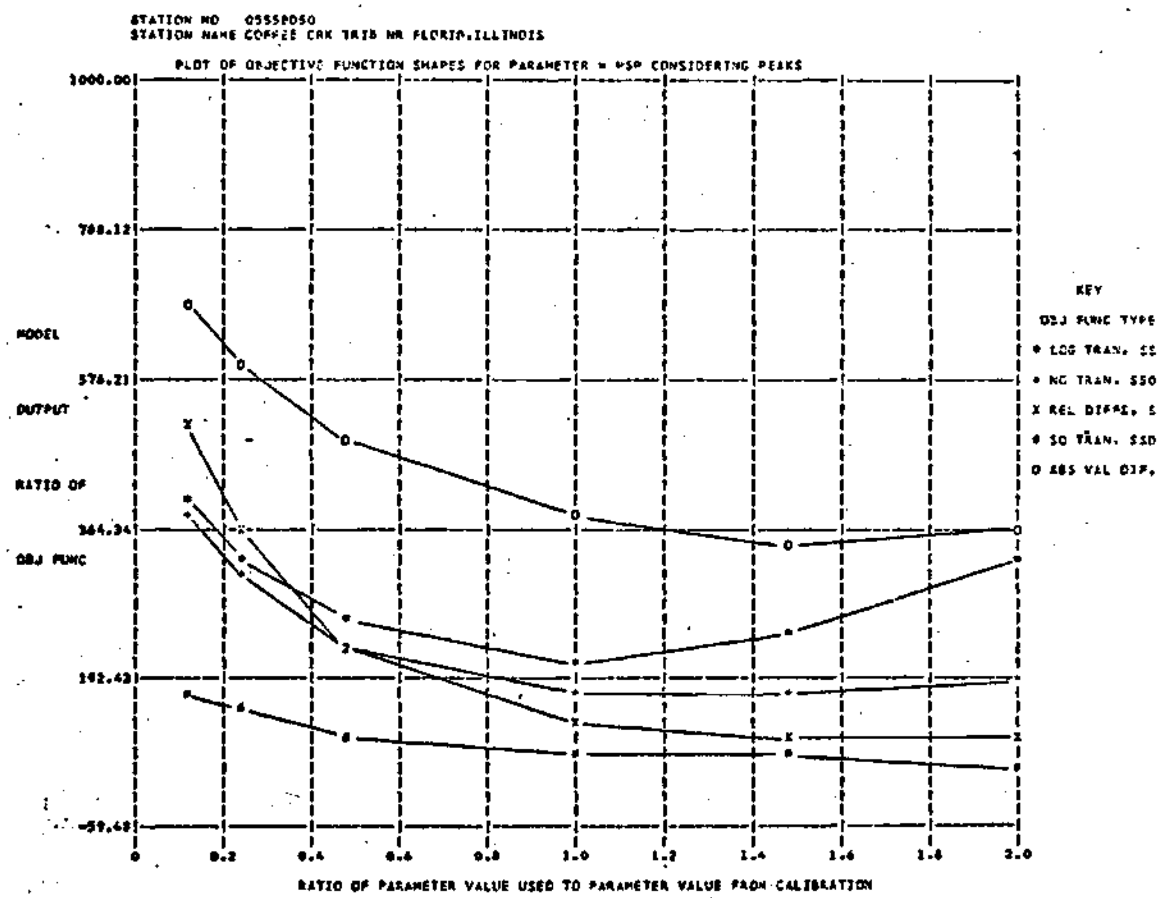

Figure C.34 Variation of Various Objective Function Forms as the Parameter PSP Varies about its Calibrated Value.

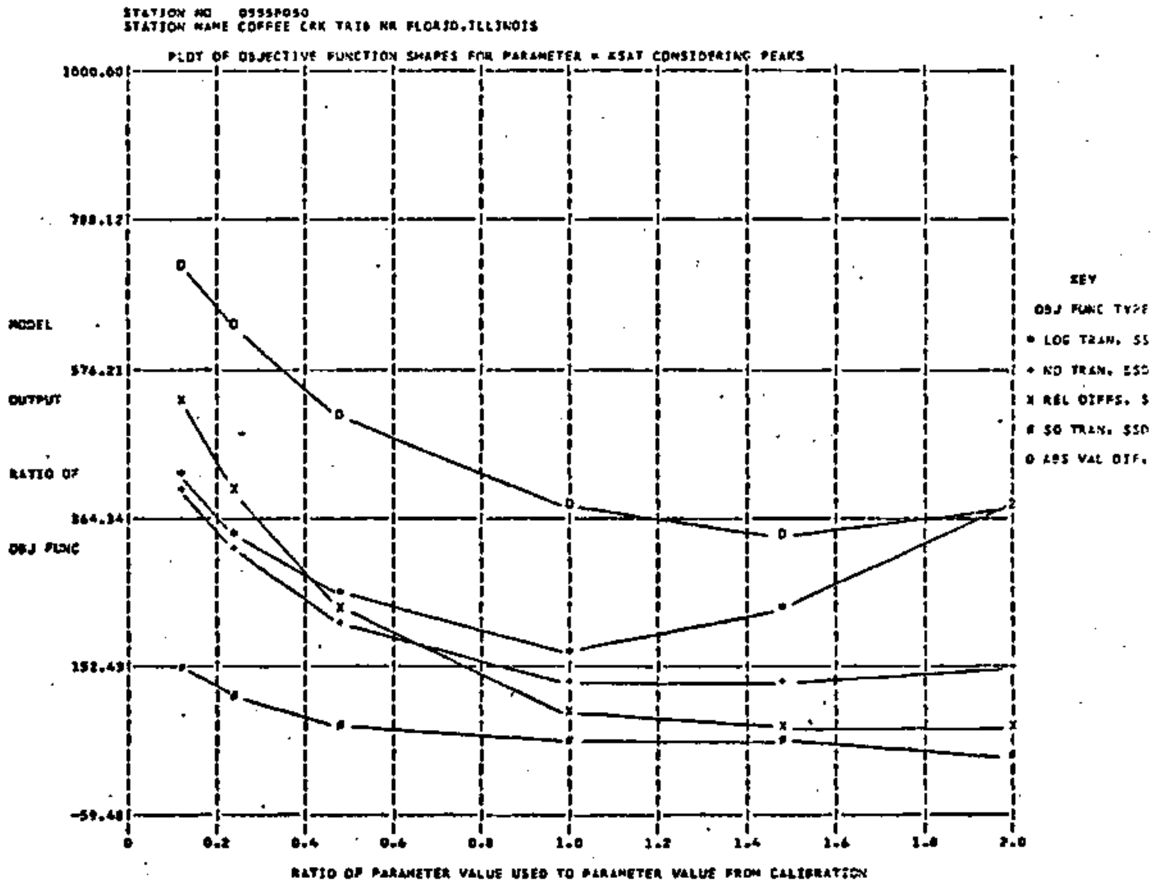

Figure C.35 Variation of Various Objective Function Forms as the Parameter KSAT varies about its Calibrated Value.

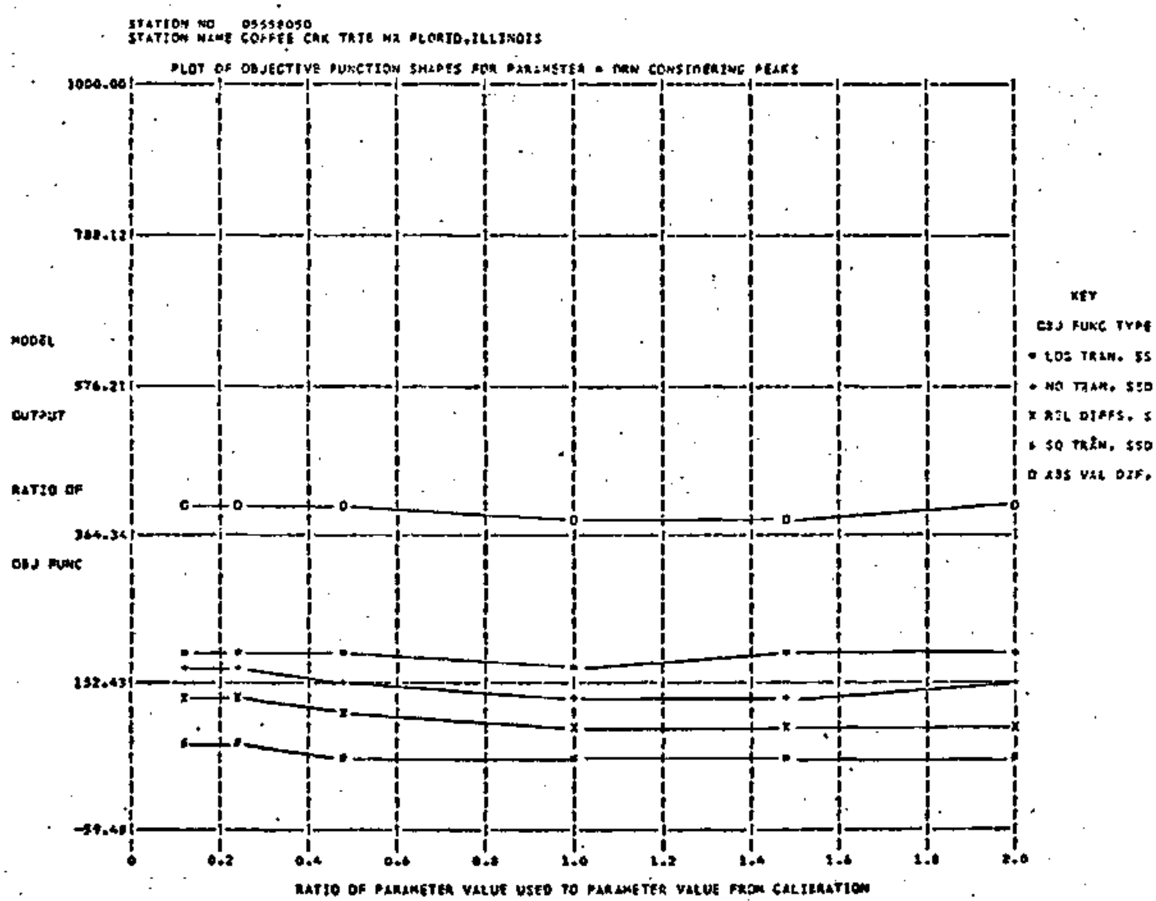

Figure C.36 Variation of Various Objective Function Forms as the Parameter DRN varies about its Calibrated Value.

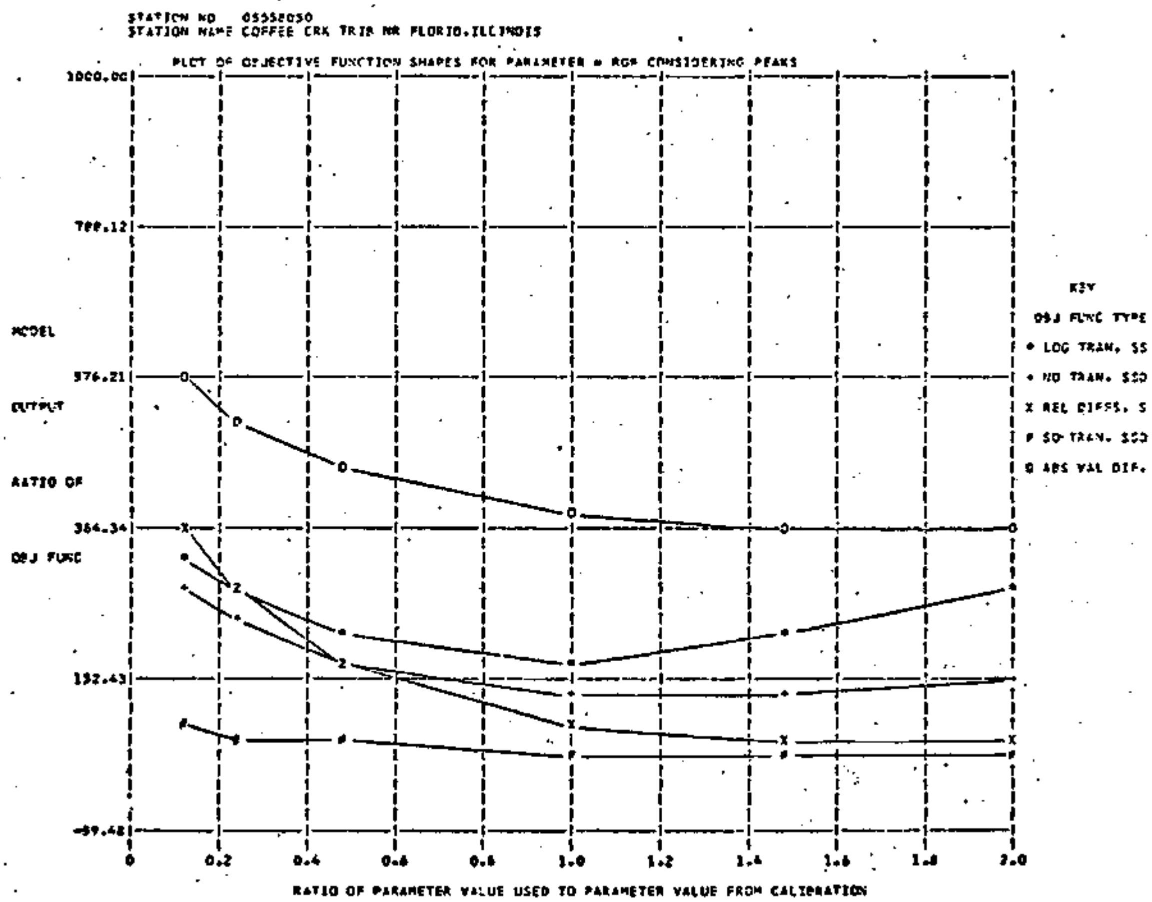

Figure C.37 Variation of Various Objective Function Forms as the Parameter RGF varies about its Calibrated Value.

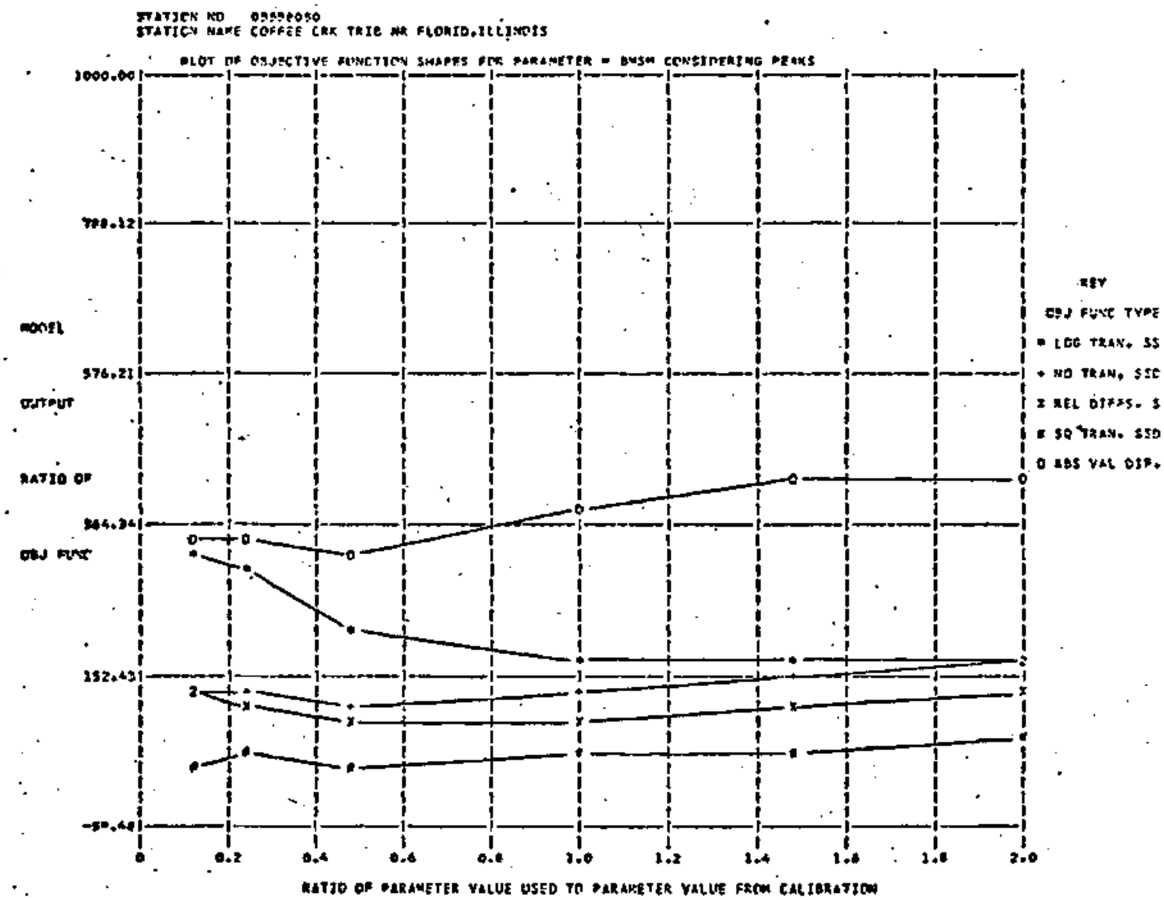

Figure C.38 Variation of Various Objective Function Forms as the Parameter BMSM varies about its Calibrated Value.

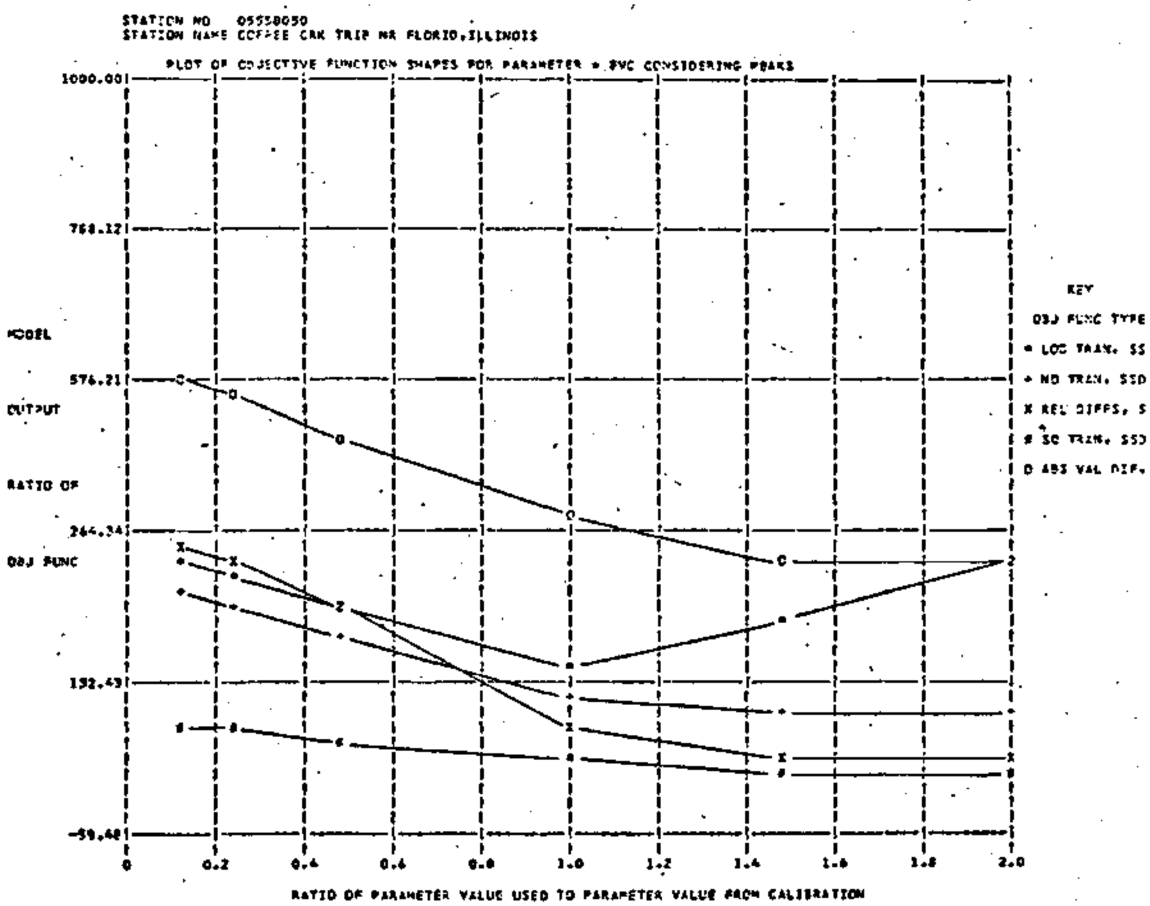

Figure C.39 Variation of Various Objective Function Forms as the Parameter EVC varies about its Calibrated Value.

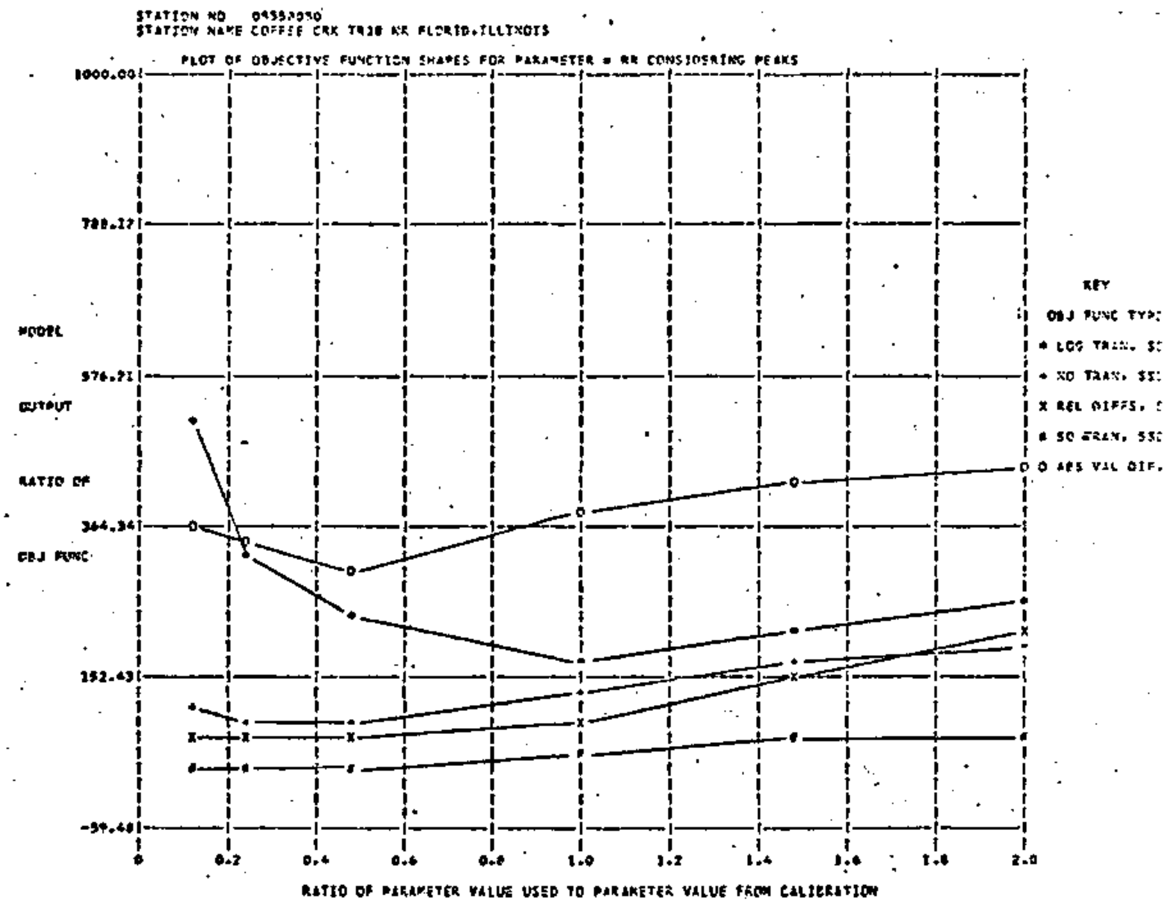

Figure C.40 Variation of Various Objective Function Forms as the Parameter RR varies about its Calibrated Value.

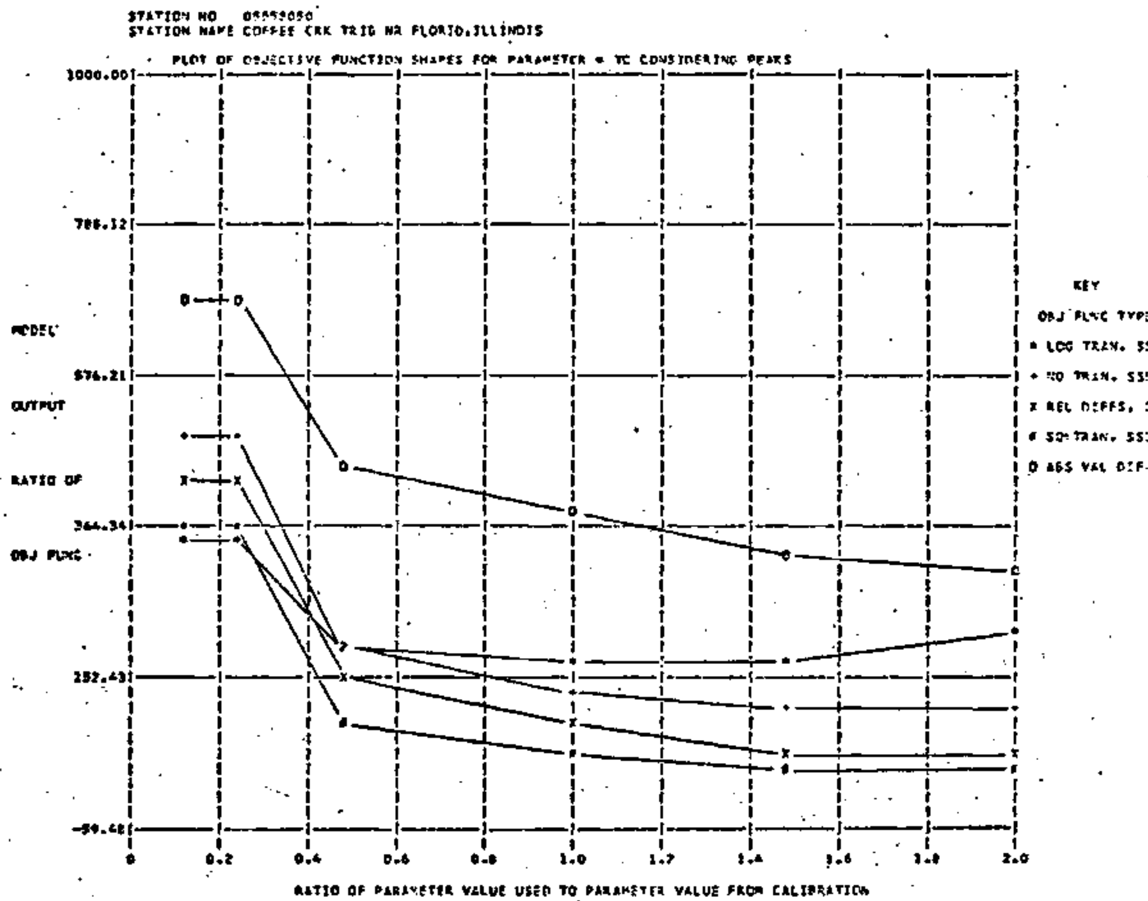

Figure C.42 Variation of Various Objective Function Forms as the Parameter TC varies about its Calibrated Value.

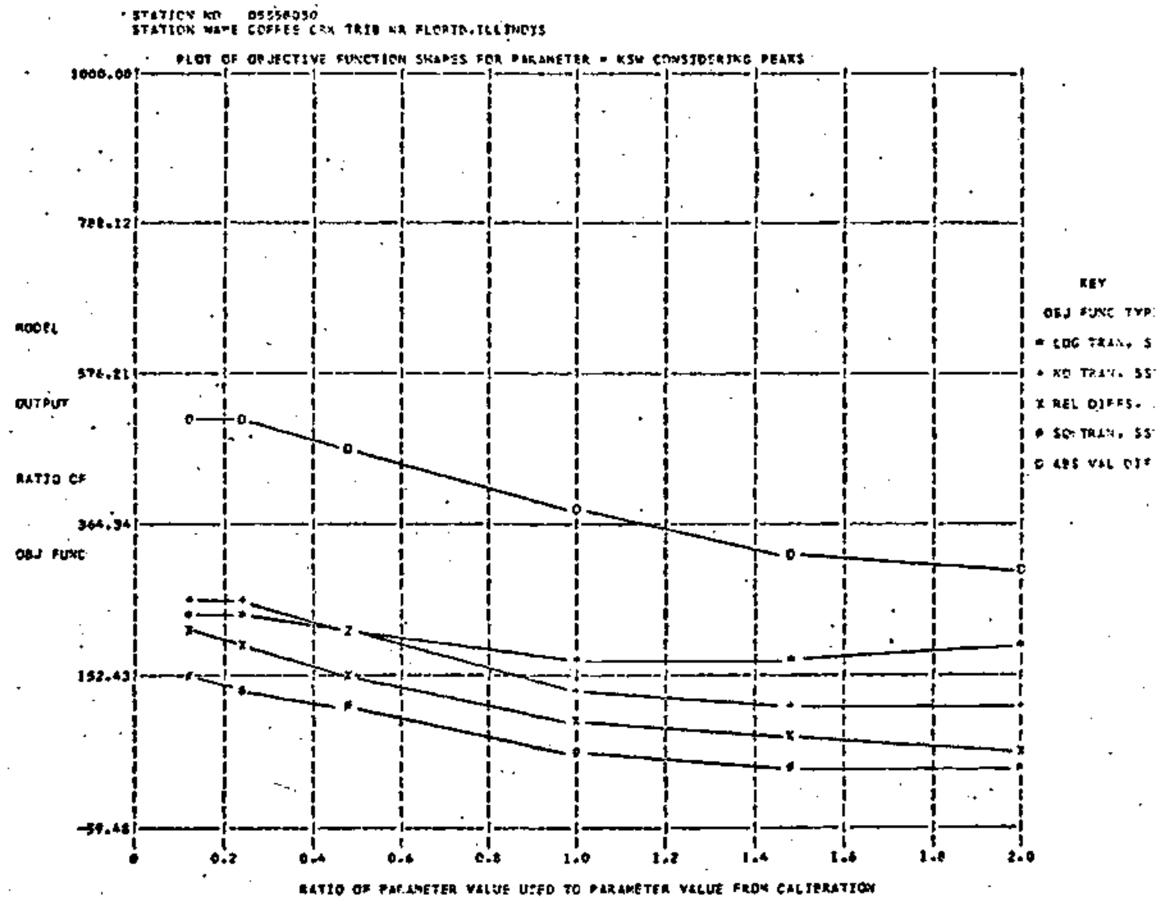

Figure C.41 Variation of
Various Objective Function
Forms as the Parameter KSW
varies about its Calibrated
Value.

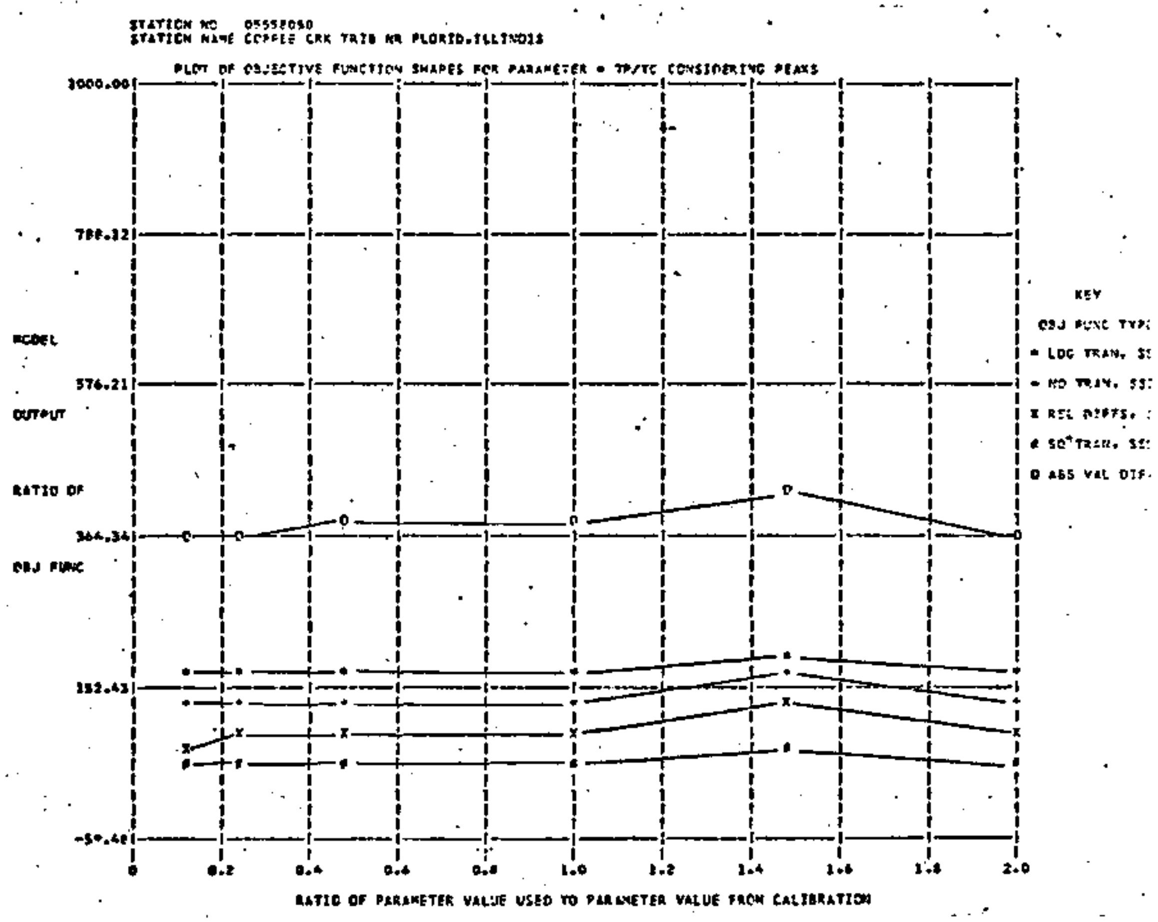

Figure C.43 Variation of Various Objective Function Forms as the Parameter TP/TC varies about its Calibrated Value.

APPENDIX D

The tables presented in this appendix furnish data which pertains to the sites used for this study. Information is given for the 228 sites used and this information is grouped by state. The tables may be classified into four main categories.

The first category provides information with respect to location for each of the 228 sites. Only Table D.1 belongs to this category. The data provided includes the 8-digit U.S. Geological Survey streamflow station number, the station name, the county in which it is located, its latitude, longitude and size of its drainage area. Table D.1 also assigns a sequence number, which is no larger than 228, to each of these sites as a means to more easily reference the stations. These reference numbers are used to plot the locations of these sites in Figure 9.

The second category provides information concerning the basin characteristics determined for these sites. Table D.2 presents the values determined for the seventeen descriptive basin characteristics. Tables D.3 through D.5 are concerned with the soils for each of these basins. Table D.3 gives the area of the basin, in percent of the total drainage area, covered by soils of a particular textural class. Table D.4 gives the percent of the total drainage area which could be considered covered by sand, silt, clay and coarse material. Table D.5 presents the ten soils characteristics determined for this study based on the information concerning soils distribution in Tables D.3

and D.4, data obtained from soil surveys and mositure dependent properties of soils. Table D.6 presents the three climatic characteristics determined for these sites.

The third category provides information required to determine whether or not the parameter values available at a site were acceptable for developing the relationships desired by this study. Table D.6 presents the final calibrated parameter values for PSP, KSAT, RGF, BMSM, KSW and TC. These are the six parameters for which predicting equations are developed in this study. The calibrations which produced these parameter values are subject to tests concerning the calibration itself and the composition of the data set used in the final calibration. Table D.8 lists the error measures and statistics comparing the observed data with results of simulation using the calibrated parameters. This information is used to judge the calibration. Table D.9 gives the distribution of the type of storm events which were used in the calibration of each of the 228 sites. This allows analysis of the data set composition to determine whether or not the calibration was performed over a sufficient range of storm events which would insure that all parameters were properly calibrated.

The fourth and final category provides the results of applying the predicting equations and applications procedure to produce values for the six parameters. Only Table D.10 belongs to this category. The predicted parameters are grouped by predicting equation set. The order is (1) LARGE, (2) SMALL, (3) SOUTH, (4) NORTH, (5) GEORGIA, (6) ILLINOIS, (7) MISS, and (8) TENN. Table D.10 presents the resulting parameters for all sites which pertain to a predicting equation set. Thus, the six parameters are determined for all 228 sites using the equations developed for the samples labeled LARGE and SMALL. However, only the sites in the defined South region had the six parameters determined from the equations developed for the sample labeled SOUTH. The remaining prediction equation sets, NORTH, GEORGIA, ILLINOIS, MISS and TENN, were applied similarly to the SOUTH set. This means that any particular site could have a maximum of four sets of predicted parameters (LARGE, SMALL, region and state) or a minimum of three sets (LARGE, SMALL, region or state).

Table D.1 List of 228 Drainage Basin Sites, by States, Used for Study

SEQUENCE NO.	STATION NO.	STATION IDENTIFICATION	COUNTY NAME	LATITUDE DEG	LATITUDE MIN	LATITUDE SEC	LONGITUDE DEG	LONGITUDE MIN	LONGITUDE SEC	DRAINAGE AREA SQ. MILES
ALABAMA										
1	02342200	PHELPS CRK NR OPELIKA, AL	LEE	32	33	45	85	16	30	7.47
2	02343700*	STEVENSON CRK NR HEADLAND, AL	HENRY	31	21	20	85	11	09	12.40
3	02362745	HURRICANE CRK NR CLAYTON, AL	BARBOUR	31	54	00	85	34	50	4.40
4	02363055	MORRIS BR NR VICTORIA, AL	COFFEE	31	27	47	85	53	57	2.17
5	02365310	GRANTS BR TRIB NR FADETTE, AL	GENEVA	31	02	21	85	35	11	1.50
6	02371200*	INDIAN CRK NR TROY, AL	PIKE	31	48	50	86	07	22	8.88
7	02372510	CATOE CRK NR ANDALUSIA, AL	COVINGTON	31	09	54	86	36	20	2.46
8	02399800*	L TERRAPIN CRK NR BORDEN SPRINGS,AL	CLEBURNE	33	54	00	85	28	00	15.90
9	02400033	NANCES CRK NR WHITE PLAINS, AL	CALHOUN	33	50	43	85	40	00	4.60
10	02400693	JACKS CRK NR FT PAYNE, AL	DEKALB	33	25	10	85	48	00	6.76
11	02407900*	PAINT CRK NR MARBLE VALLEY, AL	COOSA	32	02	07	86	25	15	13.50
12	02408340	LITTLE HATCHET CRK NR GOODWATER, AL	CLAY	33	07	31	86	05	30	9.44
13	02410000*	PATERSON CRK NR CENTRAL, AL	ELMORE	32	40	54	86	07	40	4.95
14	02412320	ELDER CRK NR DEMPSY, AL	CLAY	33	27	48	85	46	33	1.79
15	02413400*	WEDOWEE CRK ABOVE WEDOWEE, AL	RANDOLPH	33	19	56	85	21	39	6.50
16	02414800*	HARBUCK CRK NR HACKNEYVILLE, AL	CLAY	33	07	15	85	56	46	6.70
17	02417400	STEARNS CRK NR SEMAN, AL	ELMORE	32	42	55	86	05	21	1.28
18	02421300*	IVY CRK AT MULBERRY, AL	AUTAUGA	32	27	25	86	46	45	10.50
19	02427013	CAINE CRK NR SAFFORD, AL	DALLAS	32	17	42	87	20	22	2.67
20	02437800*	BARN CRK NR HACKLEBURG, AL	MARION	34	10	34	87	47	21	12.90
21	02437900*	WOODS CRK NR HAMILTON, AL	MARION	34	07	34	87	54	16	14.10
22	02449400*	JONES CRK NR EPES, AL	SUMTER	32	41	25	88	10	12	11.70
23	02450400*	DORSEY CRK NR ARKADELPHIA, AL	CULLMAN	34	57	10	87	00	14	13.00
24	02451550	JAYBIRD CRK NR WEST POINT, AL	CULLMAN	34	15	08	86	59	54	1.42
25	02451750*	WEST CRK NR BALDWIN, AL	CULLMAN	34	11	54	86	56	03	1.64
26	02452900	CHEATAM CRK NR CARBON HILL, AL	WALKER	33	53	20	87	27	00	4.77
27	02462600*	BLUE CRK NR OAKMAN, AL	TUSCALOOSA	33	31	17	87	29	07	5.70
28	02465205*	JAY CRK NR COKER, AL	TUSCALOOSA	33	13	30	87	41	50	3.56
29	02471026	WATSON CRK NR STOCKTON, AL	BALDWIN	31	01	50	87	50	00	2.25
30	02479583	FLAT CRK NR WILMER, AL	MOBILE	30	46	50	88	24	00	6.30
31	03574405	LITTLE DRY CRK NR GARTH, AL	JACKSON	34	44	20	86	19	10	3.91
32	03585380	W F ANDERSON CRK NR LEXINGTON, AL	LAUDERDALE	34	58	23	87	17	05	5.92
GEORGIA										
33	02189020	INDIAN CRK NR CARNESVILLE, GA	FRANKLIN	34	21	20	83	17	16	7.63
34	02189030	STEPHENS CRK TRIB AT CARNESVILLE,GA	FRANKLIN	34	21	51	83	13	16	0.39
35	02191270	SCULL SHOAL CRK NR DANIELSVILLE, GA	MADISON	34	09	30	83	09	51	8.75
36	02191280*	MILL SHOAL CRK NR ROYSTON, GA	HART	34	16	13	83	06	08	0.32
37	02191600	DOUBLE BR NR DANIELSVILLE, GA	MADISON	34	06	06	83	14	11	4.77
38	02191750	FORK CRK AT CARLTON, GA	MADISON	34	02	55	83	01	16	16.00
39	02192300*	HOG FK FISHING CRK NR TIGNALL, GA	WILKES	33	49	05	82	45	21	.10
40	02192400	ANDERSON MILL CRK NR DANBURG, GA	WILKES	33	48	35	82	41	35	5.49
41	02192420	ANDERSON MILL CRK TRB NR DANBURG,GA	WILKES	33	49	42	82	41	13	0.92
42	02193500	ROCKY CRK NR WASHINGTON, GA	WILKES	33	42	55	82	44	42	1.14
43	02201110	GRAY COAT CRK NR BARTOW, GA	JEFFERSON	32	52	25	82	26	34	8.36
44	02201160	BOGGY CUT CRK NR WADLEY, GA	JEFFERSON	32	53	42	82	24	02	7.05

Table D.1 , continued

SEQUENCE NO.	STATION NO.	STATION IDENTIFICATION	COUNTY NAME	LATITUDE DEG	LATITUDE MIN	LATITUDE SEC	LONGITUDE DEG	LONGITUDE MIN	LONGITUDE SEC	DRAINAGE AREA SQ. MILES
45	02201830	HOCKER BR TRIB NR MILLEN, GA	JENKINS	32	39	34	81	59	2	4.38
46	02202910*	TEN MILE CRK TRIB AT PULASKI, GA	CANDLER	32	23	18	81	58	17	1.14
47	02202950	CYPRESS FLAT CRK NR COLLINS, GA	TATTNAL	32	13	09	82	07	14	1.39
48	02208200	BEAVERDAM C TRIB AT BOLD SPRINGS,GA	WALTON	33	53	59	83	47	36	1.03
49	02211459	BIG TOWALIGA CRK NR BARNESVILLE, GA	LAMAR	33	04	20	84	11	04	2.36
50	02215280	LITTLE HOUSE C TRIB NR REBECCA, GA	BEN HILL	31	50	05	83	22	14	2.45
51	02216610*	OCMULGEE R TRIB NR LUMBER CITY, GA	WHEELER	31	58	53	82	38	25	3.23
52	02217250	BUFFALO CRK TRIB NR JEFFERSON, GA	JACKSON	34	05	00	83	38	01	0.39
53	02217400*	MULBERRY R TRIB NR WINDER, GA	JACKSON	34	03	53	83	39	45	2.68
54	02217660	LITTLE CURRY CRK NR JEFFERSON, GA	JACKSON	34	08	25	83	32	09	0.87
55	02218100	PORTERS CRK AT WATKINSVILLE, GA	OCONEE	33	50	56	83	23	42	1.95
56	02223700	INDIAN CRK TRIB NR SCOTT, GA	LAURENS	32	33	22	82	44	33	2.13
57	02224200	MERCER CRK NR SOPERTOWN, GA	TREUTLEN	32	26	38	82	41	30	16.10
58	02225330	BEAVER CRK NR COBBTOWN, GA	TATTNALL	32	16	52	82	11	27	9.58
59	02315980	ALAPAHA R TRIB NR OCILLA, GA	IRWIN	31	33	38	83	21	28	1.21
60	02316220	LITTLE BRUSHY CRK TRIB NR OCILLA,GA	IRWIN	31	36	30	83	13	56	1.65
61	02316260	ALAPAHA R TRIB#4 NR WILLACOOCHEE,GA	BERRIEN	31	16	50	83	03	45	4.16
62	02317710*	WITHLACOOCHEE R TRB NR NASHVILLE,GA	BERRIEN	31	11	54	83	17	17	0.86
63	02317760	LITTLE RIVER NR ASHBURN, GA	TURNER	31	41	33	83	42	16	8.54
64	02317765	NEWELL BR NR WORTH, GA	TURNER	31	44	20	83	43	30	0.98
65	02317770	NEWELL BR NR ASHBURN, GA	TURNER	31	41	50	83	41	56	6.48
66	02317775	DANIELS CRK NR ASHBURN, GA	TURNER	31	40	40	83	45	06	1.11
67	02317780	LIME SINK CRK NR SYCAMORE, GA	TURNER	31	36	20	83	40	31	0.68
68	02317795	MILL CRK NR TIFTON, GA	TIFT	31	29	46	83	23	15	6.21
69	02317845*	WARRIOR CRK TRIB NR SYLVESTER, GA	WORTH	31	32	54	83	49	11	1.64
70	02317905	LITTLE CRK NR OMEGA, GA	TIFT	31	23	35	83	38	00	4.22
71	02317910	TY TY CRK TRIB NR CROSSLANDS, GA	COLQUITT	31	19	17	83	37	24	2.07
72	02318015	BULL CRK NR NORMAN PARK, GA	COLQUITT	31	13	13	83	37	20	1.36
73	02318020	BULL CRK TRIB NR ELLENTON, GA	COLQUITT	31	09	19	83	37	06	0.27
74	02327350*	OCHLOCKONEE R TRIB NR COOLIDGE, GA	THOMAS	31	01	33	83	57	32	1.81
75	02327400	SALLYS BR TRIB NR SALE CITY, GA	MITCHELL	31	14	46	84	01	40	3.70
76	02346193	SCOTT CRK NR TALBOTTON, GA	TALBOT	32	39	48	84	36	06	3.36
77	02346210	KIMBROUGH CRK NR TALBOTTON, GA	TALBOT	32	41	19	84	30	48	6.62
78	02346217*	CELEOTH CRK NR MANCHESTER, GA	TALBOT	32	49	20	84	36	16	2.82
79	02350520	ABRAMS CRK TRIB NR DOLES, GA	WORTH	31	40	46	83	48	04	3.77
80	02381100	MOUNTAINTOWN CRK TRIB NR ELLIJAY,GA	GILMER	34	42	04	84	31	54	2.41
81	02381600*	FAWCETT CRK NR TALKING ROCK, GA	GILMER	34	34	17	84	27	55	9.26
82	02381900	BALL CRK NR TALKING ROCK, GA	PICKENS	34	31	52	84	34	11	3.50
83	02382600	DRY CRK AT OAKMAN, GA	GORDON	34	33	13	84	42	27	3.06
84	02382900	PINE LOG CRK NR RYDAL, GA	BARTOW	34	22	02	84	42	45	12.80
85	02383000	ROCK CRK NR FAIRMOUNT, GA	GORDON	34	21	30	84	46	50	5.61
86	02387300	DEAD MANS BR NR RESACA, GA	GORDON	34	35	44	84	52	11	0.17
87	02387560*	OOTHKALOOGA C TRB AT ADAIRSVILLE,GA	BARTOW	34	21	34	84	55	20	3.56
88	02387700	ROCKY CRK AT CURRYVILLE, GA	GORDON	34	26	44	85	05	12	9.41
89	02387800	BAILEY CRK NR VILLANOW, GA	WALKER	34	40	10	85	05	40	3.82
90	02388200*	MOSS CRK TRIB NR SUMMERVILLE, GA	CHATTOOGA	34	25	14	85	16	35	6.02
91	02388400	JIMMY LONG CRK NR SHANNON, GA	FLOYD	34	18	53	85	05	47	3.00
92	02397750	DUCK CRK ABOVE LAFAYETTE, GA	WALKER	34	42	17	85	19	40	6.82
93	03566660	SUGAR CRK NR RINGGOLD, GA	CATOOSA	34	58	14	85	01	29	4.44

Table D.1 , continued

SEQUENCE NO.	STATION NO.	STATION IDENTIFICATION	COUNTY NAME	LATITUDE DEG	LATITUDE MIN	LATITUDE SEC	LONGITUDE DEG	LONGITUDE MIN	LONGITUDE SEC	DRAINAGE AREA SQ. MILES
54	03566687	L CHICKAMAUGA C TRIB NR RINGGOLD,GA	CATOOSA	34	51	36	85	08	40	3.36
ILLINOIS										
55	03338100	*SALT FORK TRIB NR CATLIN, IL	VERMILION	40	03	55	87	46	05	2.20
56	03344250	*EMBARRAS R TRIB NR GREENUP, IL	CUMBERLAND	39	14	00	88	09	20	0.08
57	03380300	*DUMS CRK TRIB NR IUKA, IL	MARION	38	37	35	88	49	20	0.08
58	03380450	WHITE FEATHER CRK NR MARLOW, IL	JEFFERSON	38	20	40	88	46	50	0.45
59	03381600	*LITTLE WABASH R TRB NR NEW HAVEN,IL	WHITE	37	55	50	88	09	55	0.16
100	03382025	L SALINE CRK TRIB NR GOREVILLE, IL	WILLIAMSON	37	36	28	88	58	44	0.51
101	05418800	MILL CRK NR SCALES MOUND, IL	JO DAVIESS	42	27	10	90	15	10	0.80
102	05437600	ROCK R TRIB NR ROCKTON, IL	WINNEBAGO	42	23	00	89	05	50	1.86
103	05438850	MD B OF S B KISHWAUKEE R N MALTA,ILD	EKALB	41	51	20	88	53	10	1.72
104	05439550	*S BR KISHWAUKEE R TRIB NR IRENE, IL	WINNEBAGO	42	10	38	88	56	50	1.80
105	05448050	*SAND CRK NR MILAN, IL	ROCK ISLAND	41	24	05	90	36	20	0.20
106	05469750	*ELLISON CRK TRIB NR ROSEVILLE, IL	WARREN	40	44	00	90	45	35	0.26
107	05495200	*LITTLE CRK NR BRECKENRIDGE, IL	HANCOCK	40	15	00	91	19	15	1.48
108	05502120	*KISER CRK TRIB NR BARRY, IL	PIKE	39	41	05	91	00	00	0.78
109	05527050	*PRAIRIE CRK NR FRANKFORT, IL	WILL	41	26	12	87	50	42	0.83
110	05536265	LANSING DITCH NR LANSING, IL	COOK	41	31	40	87	31	45	8.84
111	05541750	MAZON R TRIB NR GARDNER, IL	GRUNDY	41	05	36	88	20	35	4.52
112	05551800	FOX R TRIB NR FOX, IL	KENDALL	41	36	28	88	28	43	0.45
113	05554600	MUD CRK TRIB NR ODELL, IL	LIVINGSTON	41	00	50	88	38	36	0.14
114	05555400	VERMILION R TRIB AT LOWELL, IL	LASALLE	41	14	30	89	00	35	0.13
115	05557100	BUREAU CRK TRIB NR WYANET, IL	BUREAU	41	18	40	89	35	20	0.38
116	05558050	COFFEE CRK TRIB NR FLORID, IL	PUTNAM	41	14	25	89	18	00	0.03
117	05558075	*COFFEE CRK TRIB NR HENNEPIN, IL	PUTNAM	41	14	35	89	18	25	0.22
118	05566000	*EAST BR PANTHER CRK NR GRIDLEY, IL	LIVINGSTON	40	46	00	88	54	35	6.30
119	05572100	WILDCAT CRK TRIB NR MONTICELLO, IL	PIATT	40	01	37	88	38	24	0.10
120	05577520	SPRING CRK TRIB AT SPRINGFIELD, IL	SANGAMON	39	50	04	89	37	14	1.27
121	05577700	*SANGAMON R TRIB AT ANDREW, IL	SANGAMON	39	53	45	89	38	50	1.52
122	05586500	HURRICANE CRK NR ROODHOUSE, IL	GREENE	39	29	20	90	25	00	2.33
123	05587850	*CAHOKIA CRK TRIB NR CARPENTER, IL	MADISON	38	52	40	89	54	30	0.45
124	05591500	ASA CRK AT SULLIVAN, IL	MOULTRIE	39	37	11	88	36	17	7.93
125	05594200	WILLIAMS CRK NR CORDES, IL	WASHINGTON	38	19	40	89	28	35	1.84
126	05595550	*MARYS R TRIB AT CHESTER, IL	RANDOLPH	37	55	27	89	48	26	0.61
127	05596100	ANDY CRK TRIB AT VALIER, IL	FRANKLIN	38	01	15	89	02	40	1.00
128	05599640	*GREEN CRK TRIB NR JONESBORO, IL	UNION	37	27	55	89	18	40	0.44
MISSISSIPPI										
129	02429980	POLLARD MILL BR NR PADEN, MS	TISHOMINGO	34	39	10	88	15	00	2.05
130	02435300	COW PIKE PASS NR TUPELO, MS	LEE	34	16	00	88	37	10	0.14
131	02435400	*CLEAR BR NR TUPELO, MS	LEE	34	15	30	88	39	50	0.75
132	02437550	NICHOLS CRK NR QUINCY, MS	MONROE	33	54	20	88	21	05	0.54
133	02440020	CHUQUATONCHEE C TRIB NR TREBLOC, MS	CHICKASAW	33	50	25	88	48	20	0.72
134	02441220	*SAND CRK TRIB NR MAYHEW, MS	OKTIBBEHA	33	28	40	88	43	20	0.44
135	02447340	CYPRESS CRK TRIB AT BRADLEY, MS	OKTIBBEHA	33	22	20	88	59	00	0.60
136	02475220	L ROCK CRK TRIB NR LITTLE ROCK, MS	NEWTON	32	31	00	89	01	00	0.22
137	02477090	POWERS CRK NR ROSE HILL, MS	JASPER	32	12	00	89	02	00	0.45
138	02478600	GRANNY BR AT PIAVE, MS	GREENE	31	23	30	88	44	50	0.69

Table D.1 , continued

SEQUENCE NO.	STATION NO.	STATION IDENTIFICATION	COUNTY NAME	LATITUDE			LONGITUDE			DRAINAGE AREA SQ. MILES
				DEG	MIN	SEC	DEG	MIN	SEC	
139	02479165*	MOSQUITO BR AT BENNDALE, MS	GEORGE	30	51	40	88	49	30	0.22
140	02481505	MILL CRK TRIB NR LIZANA, MS	HARRISON	30	35	50	89	19	10	2.29
141	02485780	CRANE CRK AT JACKSON, MS	HINDS	32	21	00	90	09	50	0.45
142	02485900	KEELY CRK NR BRANDON, MS	RANKIN	32	17	58	90	03	44	1.09
143	02487670	BOGGANS DITCH NR MENDENHALL, MS	SIMPSON	31	53	10	89	53	20	0.91
144	02487710	BARRETS BR NR PINOLA, MS	SIMPSON	31	52	50	90	02	40	0.88
145	02488550	GOINES DRAW NR PRENTISS, MS	SIMPSON	31	47	00	89	52	40	0.34
146	02488680	PLUM DITCH NR PRENTISS, MS	JEFF. DAVIS	31	35	20	89	56	40	0.23
147	02489030*	ELPERS DRAW NR COLUMBIA, MS	MARION	31	12	00	89	58	00	0.91
148	02489160	KOKOMO DRAW AT KOKOMO, MS	MARION	31	11	30	90	00	00	1.26
149	07029252	POOL BR NR RIPLEY, MS	TIPPAH	34	42	50	88	47	20	1.24
150	07267200*	CRACKER DITCH NR PONTOTOC, MS	PONTOTOC	34	17	30	89	11	40	0.23
151	07277550*	JAMES WOLF CRK TRIB NR LOOXAHOMA,MS	TATE	34	36	45	89	50	30	0.29
152	07282300	SABOUGLA CRK TRIB AT SABOUGLA, MS	CALHOUN	33	46	10	89	27	30	0.50
153	07285700	LONG CRK NR CASCILLA, MS	TALLAHATCHIE	33	51	40	89	59	05	1.64
154	07287140*	MARTIN LAKE TRIB AT SIDON, MS	LEFLORE	33	27	10	90	12	30	0.26
155	07287520*	SHORT CRK TRIB NR YAZOO CITY, MS	YAZOO	32	48	15	90	22	20	1.49
156	07288568	QUIVER R TRIB NR SCHLATER, MS	LEFLORE	33	38	30	90	24	30	0.18
157	07289640	PANTHER CRK NR FLORA, MS	MADISON	32	33	57	90	10	22	0.26
158	07290220	DRY DRAW NR BROOKHAVEN, MS	LINCOLN	31	36	35	90	25	50	0.20
159	07290525*	WHITE OAK CRK TRIB NR UTICA, MS	HINDS	32	04	00	90	31	35	1.36
160	07290910	SPANISH BAYOU AT NATCHEZ, MS	ADAMS	31	31	50	91	23	25	2.59
161	07294400*	OBSERVERS DRAW NR DOLOROSO, MS	WILKINSON	31	19	10	91	21	20	0.22
162	07373550*	MOORES BRANCH NR WOODVILLE, MS	WILKINSON	31	05	20	91	14	30	0.21
163	07375235	TANGIPAHOA R TRIB NR MCCOMB, MS	PIKE	31	12	30	90	31	40	2.71
164	07376665	STOCK POND DRAW NR LIBERTY, MS	AMITE	31	10	15	90	45	20	0.38
165	07376760	CRS DRAW NR LIBERTY, MS	AMITE	31	06	50	90	54	10	0.80
MISSOURI										
166	05497700	BRIDGE CRK BR NR BARING, MO	KNOX	40	15	30	92	13	00	2.54
167	05502700	EASDALE BR NR SHELBYVILLE, MO	SHELBY	39	48	17	92	00	27	0.71
168	05503000*	OAK DALE BR NR EMDEN, MO	SHELBY	39	45	30	91	55	08	2.64
169	06815550	STAPLES BR NR BURLINGTON JUNC, MO	ATCHISON	40	26	15	95	12	05	0.49
170	06816000*	MILL CRK AT OREGON, MO	HOLT	39	58	55	95	07	37	4.90
171	06820000	WHITE CLOUD CRK NR MARYVILLE, MO	NODAWAY	40	23	22	94	54	33	6.06
172	06897700	GRAND R TRIB NR UTICA, MO	LIVINGSTON	39	44	22	93	38	18	1.44
173	06902500	HAMILTON BR NR NEW BOSTON, MO	LINN	39	57	08	92	54	08	2.51
174	06902800*	ONION BR AT ST CATHERINE, MO	LINN	39	47	46	92	59	17	1.04
175	06907200	SHAVER CRK TRIB NR CLIFTON CITY, MO	PETTIS	38	45	29	93	04	25	1.65
176	06908300*	TRENT BR NR WAVERLY, MO	LAFAYETTE	39	12	06	93	34	46	0.97
177	06909700	PETITE SALINE C TRIB NR BELLAIR, MO	COOPER	38	50	34	92	50	31	0.49
178	06910250*	THAXLER BR NR COLUMBIA, MO	BOONE	38	51	15	92	19	45	0.55
179	06918700	OAK GROVE BR NR BRIGHTON, MO	GREENE	37	24	11	93	21	21	1.30
180	06919200	SAC R TRIB NR CAPLINGER MILLS, MO	CEDAR	37	48	22	93	51	00	0.14
181	06921740*	BRUSHY CRK NR BLAIRSTOWN, MO	HENRY	38	31	42	94	00	37	1.15
182	06925300*	PRAIRIE BR NR DECATURVILLE, MO	LACLEDE	37	52	30	92	42	30	1.48
183	06927100	DUANE BR NR KINGDOM CITY, MO	CALLAWAY	38	56	20	91	49	40	0.54
184	06931500	LITTLE BEAVER CRK NR ROLLA, MO	PHELPS	37	56	06	91	50	11	6.41
185	06935600	SHOTWELL CRK NR ELLISVILLE, MO	ST LOUIS	38	37	05	90	35	00	0.81

Table D.1 , continued

SEQUENCE NO.	STATION NO.	STATION IDENTIFICATION	COUNTY NAME	LATITUDE DEG	LATITUDE MIN	LATITUDE SEC	LONGITUDE DEG	LONGITUDE MIN	LONGITUDE SEC	DRAINAGE AREA SQ. MILES
186	07011200	LOVE CRK NR SALEM, MO	DENT	37	38	10	91	33	35	0.89
187	07011500	GREEN ACRE BR NR ROLLA, MO	PHELPS	37	54	50	91	43	37	0.62
188	07015500*	LANES FORK NR ROLLA, MO	PHELPS	37	55	33	91	43	36	0.22
189	07017500	DRY BR NR BONNE TERRE, MO	ST FRANCOIS	37	55	46	90	27	40	3.35
190	07064300	FUDGE HOLLOW NR LICKING, MO	DENT	37	31	50	91	44	13	1.72
191	07064500*	BIG CRK NR YUKON, MO	TEXAS	37	13	57	91	50	59	8.36
192	07185500*	STAHL CRK NR MILLER, MO	LAWRENCE	37	11	42	93	50	37	3.86
TENNESSEE										
193	03313600*	W F DRAKES C TB NR FOUNTAIN HEAD,TN	SUMNER	36	33	34	86	27	26	0.95
194	03313620	W PRONG CANEY FK C NR OAK GROVE, TN	SUMNER	36	32	36	86	23	29	3.03
195	03418900	RACCOON CRK NR OLD WINESAP, TN	CUMBERLAND	35	47	12	85	08	40	1.52
196	03420360*	MUD CRK TRIB#2 NR SUMMITVILLE, TN	COFFEE	35	36	10	86	01	33	2.28
197	03420380	MUD CRK TRIB NR SUMMITVILLE, TN	COFFEE	35	36	20	86	00	24	1.03
198	03420400	MUD CRK NR SUMMITVILLE, TN	COFFEE	35	37	23	86	00	00	7.30
199	03430400*	MILL CRK AT NOLENSVILL , TN	WILLIAMSON	35	57	32	86	40	31	12.00
200	03431520	CLAYLICK CRK AT LICKTON, TN	DAVIDSON	36	18	02	86	48	37	4.13
201	03431580	EWING C AT KNIGHT RD,NR BORDEAUX,TN	DAVIDSON	36	13	55	86	48	14	13.30
202	03431600	WHITES CRK NR BORDEAUX, TN	DAVIDSON	36	12	45	86	49	29	51.60
203	03431650	VAUGHNS GAP BR AT BELLE MEADE, TN	DAVIDSON	36	05	43	86	52	38	2.66
204	03435020	RED RIVER NR NEW DEAL, TN	SUMNER	36	31	40	86	32	43	9.32
205	03435030	RED RIVER NR PORTLAND, TN	SUMNER	36	33	24	86	34	14	15.10
206	03435600*	SULPHUR F RED R T NR WHITE HOUSE,TN	ROBERTSON	36	26	52	86	42	53	3.50
207	03461200*	CROSBY CRK NR CROSBY, TN	COCKE	35	47	02	83	13	08	10.20
208	03469110	RAMSEY CRK NR PITTMAN CENTER, TN	SEVIER	35	45	33	83	20	49	2.18
209	03486225	POWDER BR NR JOHNSON CITY, TN	CARTER	36	19	03	82	16	40	4.88
210	03519610	BAKER CRK TRIB NR BINFIELD, TN	BLOUNT	35	41	56	84	02	46	2.10
211	03519630	GRIFFITTS BR NR GREENBACK, TN	BLOUNT	35	41	33	84	06	16	1.46
212	03519640	BAKER CRK NR GREENBACK, TN	BLOUNT	35	40	21	84	06	28	16.00
213	03519650*	LITTLE BAKER CRK NR GREENBACK, TN	BLOUNT	35	39	21	84	06	13	3.65
214	03535140	S FORK BEAVER CRK AT HARRISON, TN	KNOX	36	06	51	83	51	15	1.40
215	03535160	BEAVER CRK NR HALLS CROSSROADS, TN	KNOX	36	04	59	83	54	26	14.10
216	03535180*	WILLOW FORK NR HALLS CROSSROADS, TN	KNOX	36	05	59	83	54	27	3.23
217	03538900	SELF CRK NR BIG LICK, TN	CUMBERLAND	35	47	54	85	02	33	3.80
218	03539100*	BYRD CRK NR CROSSVILLE, TN	CUMBERLAND	35	53	40	85	03	38	1.10
219	03597300	WARTRACE CRK ABOVE BELL BUCKLE, TN	BEDFORD	35	37	45	86	21	22	4.99
220	03597400	WARTRACE CRK NR BELL BUCKLE, TN	BEDFORD	35	36	23	86	21	08	9.59
221	03597450	KELLY CRK TRIB NR BELL BUCKLE, TN	BEDFORD	35	36	34	86	19	11	0.73
222	03597500*	WARTRACE CRK AT BELL BUCKLE, TN	BEDFORD	35	35	16	86	20	22	16.30
223	03597550	MUSE BR NR BELL BUCKLE, TN	BEDFORD	35	34	03	86	19	28	1.86
224	03604070*	COON CRK TRIB NR HOHENWALD, TN	PERRY	35	34	07	87	40	02	0.51
225	03604080	HUGH HOLLOW BR NR HOHENWALD, TN	PERRY	35	34	59	87	40	36	1.52
226	03604090	COON C ABV CHOP HOL, N HOHENWALD,TN	PERRY	35	35	19	87	41	09	6.02
227	03604100	COON CRK NR HOHENWALD, TN	PERRY	35	36	23	87	42	43	10.10
228	07028935	TURKEY CRK TRIB NR MEDINA, TN	MADISON	35	37	34	88	47	26	1.08

Note *--One of 75 common sites in Chapter 7.

Table D.2 Values Determined for Descriptive Basin Characteristics for Sites in Study

	SAMPLE	A	P	CC	E	RMAX	L	S	RRAT	W	SHAPE
ALA	2342200	7.4700	11.2100	1.1570	646.0000	300.0000	5.2000	42.0000	57.6900	1.4400	0.2800
	2343700	12.4000	14.8700	1.1910	301.0000	258.0000	6.2000	30.0000	41.6100	2.0000	0.3200
	2362745	4.4000	8.8800	1.1940	523.0000	211.0000	3.2000	34.3000	65.9400	1.3700	0.4300
	2363055	2.1700	5.9100	1.1320	396.0000	237.0000	2.3900	49.2000	99.1600	0.9100	0.3800
	2365310	1.5900	4.9000	1.1290	245.0000	75.0000	1.5300	34.8000	49.0200	0.9800	0.6400
	2371200	8.8800	13.5600	1.2849	497.0000	245.0000	4.5200	27.6000	54.2000	1.9600	0.4300
	2372510	2.4600	7.7700	1.3970	259.0000	137.0000	2.4000	58.0000	57.0800	1.0200	0.4300
	2399800	15.9000	19.3200	1.3670	1087.0000	711.0000	9.5300	32.7000	74.6100	1.6700	0.1800
	2400033	4.6000	9.4100	1.2380	1144.0000	1106.0000	3.4800	166.0000	317.8201	1.3200	0.3800
	2400690	6.7600	15.8100	1.7150	1120.0000	475.0000	5.9100	33.0000	80.3700	1.1400	0.1900
	2407900	13.5000	16.4000	1.2590	685.0000	508.0000	7.3500	33.0000	69.1200	1.8400	0.2500
	2408340	9.9400	13.0000	1.1630	947.0000	780.0000	5.6800	32.9000	137.3200	1.7500	0.3100
	2410000	4.9500	9.1000	1.1540	616.0000	295.0000	3.6000	69.0000	81.9400	1.3800	0.3800
	2412320	1.7900	6.4000	1.3490	1295.0000	1210.0000	2.8800	135.0000	420.1399	0.6200	0.2200
	2413400	6.5000	11.4000	1.2610	1346.0000	394.0000	5.9000	42.0000	66.7800	1.1000	0.1900
	2414900	6.7000	11.8900	1.2960	856.0000	545.0000	4.5000	67.2000	121.1100	1.4900	0.3300
	2419400	1.3000	4.7500	1.1750	790.0000	195.0000	2.2200	75.3000	87.8400	0.5900	0.2600
	2421300	10.5000	14.3500	1.2490	374.0000	290.0000	8.2600	27.4000	35.1100	1.2700	0.1500
	2427013	2.6700	7.4200	1.2810	203.0000	108.0000	2.6000	39.0000	41.5400	1.0300	0.3900
	2437800	12.9000	16.6300	1.3060	811.0000	350.0000	6.2500	35.2000	56.0000	2.0600	0.3300
	2437990	14.1000	18.7400	1.4090	709.0000	390.0000	7.5900	31.5000	51.3800	1.8600	0.2400
	2440400	11.7000	14.3000	1.1550	213.0000	185.0000	5.7800	19.6000	32.0100	2.0200	0.3500
	2450200	13.0000	15.9800	1.2500	697.0000	375.0000	6.8400	26.8000	54.8200	1.9000	0.2800
	2451550	1.4200	5.1700	1.2240	984.0000	195.0000	2.2700	52.3000	85.9000	0.6300	0.2800
	2451750	1.6400	5.0200	1.1060	974.0000	225.0000	2.0500	110.5000	109.7600	0.8000	0.3900
	2453999	4.7700	9.1300	1.1770	561.0000	227.0000	3.9800	45.6000	57.0400	1.2000	0.3000
	2462600	5.7000	11.1700	1.3200	591.0000	247.0000	4.3000	65.0000	57.4400	1.3300	0.3100
	2465205	3.5600	8.5200	1.2740	334.0000	287.0000	2.9400	47.7000	97.6200	1.2100	0.4100
	2471926	2.2500	6.6000	1.2410	128.0000	180.0000	2.1300	43.8000	84.5100	1.0600	0.5000
	2475583	6.3000	10.1500	1.1410	211.0000	150.0000	4.1700	25.5000	35.9700	1.5100	0.3600
	2574405	3.9100	9.1500	1.2050	1451.0000	1065.0000	3.9400	286.0000	270.3000	0.9900	0.2500
	3595380	5.9200	11.0400	1.2800	831.0000	147.0000	5.7500	23.0000	25.5700	1.0300	0.1800
GA	2189020	7.6300	12.8800	1.3150	774.0000	222.0000	6.1400	22.2000	36.1600	1.2400	0.2000
	2189030	0.3900	2.6500	1.2150	760.0000	120.0000	0.9200	20.6000	130.4300	0.4200	0.4600
	2191270	8.7500	12.9500	1.2350	704.0000	195.0000	4.5900	21.1000	42.4800	1.9100	0.4200
	2191290	0.3200	2.2900	1.1420	863.0000	133.0000	0.5900	175.0000	225.4200	0.5400	0.9200
	2191600	4.7700	9.4300	1.2190	769.0000	150.0000	4.0400	44.0000	37.1300	1.1800	0.2900
	2191750	13.4000	23.0300	1.7490	642.0000	330.0000	10.7000	25.8000	30.8400	1.2900	0.1200
	2192300	0.3570	1.2700	1.1500	603.0000	57.0000	0.4800	394.0000	118.7500	0.2000	0.4200
	2192400	5.4900	9.9200	1.1940	565.0000	215.0000	5.0400	28.5000	42.6600	1.0900	0.2200
	2192420	0.9200	4.2400	1.2470	545.0000	160.0000	1.6700	92.0000	95.8100	0.5500	0.3300
	2193600	1.1400	4.6400	1.2260	561.0000	120.0000	1.8900	66.0000	63.4900	0.6000	0.3200
	2201110	8.3600	14.3700	1.4020	306.0000	130.0000	5.3800	19.6000	24.1600	1.5500	0.2900
	2201160	7.0500	13.3100	1.4140	293.0000	124.0000	4.1800	23.3000	29.6700	1.6900	0.4000
	2201830	4.3800	10.4400	1.4070	276.0000	157.0000	3.8600	29.6000	40.6700	1.1300	0.2900
	2202910	1.1400	4.3400	1.1470	237.0000	72.0000	1.5400	22.5000	46.7500	0.7400	0.4800
	2202950	1.3900	5.1300	1.2270	244.0000	60.0000	2.4800	26.5000	24.1900	0.5600	0.2300
	2208200	1.0300	4.2200	1.1730	912.0000	170.0000	1.5900	70.0000	106.9200	0.6500	0.4100
	2211459	2.3600	7.3900	1.3570	786.0000	170.0000	2.8000	51.4000	60.7100	0.8400	0.3000
	2215280	2.4500	7.9400	1.4310	341.0000	140.0000	2.3500	43.1000	59.5700	1.0400	0.4400

Table D.2 , continued

	SAMPLE	OVL	OVS	LCHAN	OD	ST	F	I
ALA	2342200	0.0614	570.2397	39.4700	5.2840	0.0	80.0000	0.0
	2343700	0.0854	369.5999	48.5600	3.9160	0.0	60.0000	0.0
	2362745	0.0742	570.2397	31.9300	7.2570	0.0	80.0000	0.0
	2363055	0.0672	617.7598	11.8400	5.4560	0.0	95.0000	0.0
	2365310	0.1583	168.9600	4.5000	3.0000	0.0	20.0000	0.0
	2371200	0.0807	617.7598	27.2300	3.0660	0.0	80.0000	0.0
	2372510	0.0877	327.3599	10.7800	4.3820	0.0	90.0000	0.0
	2399800	0.0542	1531.2000	78.8600	4.9600	0.0	95.0000	0.0
	2400033	0.0748	1309.4399	21.0200	4.5700	0.0	50.0000	0.0
	2400590	0.0845	1082.3999	29.8100	4.4100	0.0	50.0000	0.0
	2407900	0.0879	765.5999	41.4500	3.0700	0.0	90.0000	0.0
	2408240	0.1163	650.0798	26.3000	2.6460	0.0	90.0000	0.0
	2410000	0.0845	628.3201	12.1500	2.4550	1.0000	84.0000	0.0
	2412320	0.0674	1177.4399	12.2000	6.0160	0.0	100.0000	0.0
	2413400	0.0814	580.9000	30.0400	4.6220	0.0	70.0000	0.0
	2414900	0.0701	945.1199	25.0900	3.7430	0.0	90.0000	0.0
	2417400	0.0903	501.6001	2.8000	2.1540	0.0	90.0000	0.0
	2421300	0.1114	670.5598	31.0000	2.9520	0.0	62.0000	0.0
	2427013	0.1023	274.5598	12.4600	4.6670	0.0	10.0000	0.0
	2437800	0.0631	1703.8398	44.1830	3.4250	0.0	75.0000	0.0
	2437900	0.0867	1050.7200	34.8700	2.4730	0.0	95.0000	0.0
	2449400	0.1258	380.1599	41.4000	3.5380	0.0	5.0000	0.0
	2450200	0.0578	1052.9600	50.9800	3.9220	0.0	75.0000	0.0
	2451550	0.0706	749.7600	9.0500	6.3730	0.0	55.0000	0.0
	2451750	0.0646	807.8398	12.2500	7.4700	0.0	44.0000	0.0
	2453900	0.0763	551.3599	26.1400	5.4800	0.0	100.0000	0.0
	2462400	0.0598	902.9797	20.7400	5.3930	0.0	85.0000	0.0
	2466205	0.0671	987.3599	21.3400	5.9940	0.0	75.0000	0.0
	2471026	0.1142	311.5198	12.3500	5.4090	0.0	75.0000	0.0
	2479593	0.1616	232.3230	15.5000	2.4600	0.0	50.0000	0.0
	3574405	0.0830	1129.9199	20.0200	5.1200	0.0	90.0000	0.0
	3585380	0.1023	279.9398	24.6800	4.1690	0.0	15.0000	0.0
GA	2190020	0.1083	628.3201	44.9600	5.8970	0.1100	60.1000	0.0
	2190030	0.0839	448.7998	3.5000	8.9740	2.9400	21.8000	0.0
	2191270	0.1259	480.4800	33.6400	3.8450	0.1400	48.8000	0.0
	2191280	0.0975	395.9998	3.3700	10.5310	0.9000	28.5000	0.0
	2191600	0.1402	491.0398	37.0600	7.7690	0.0100	64.2000	0.0
	2191750	0.2708	353.7598	86.3100	6.2540	0.0100	57.3000	0.0
	2192300	0.0902	438.2400	0.9500	9.7940	0.0	59.5000	0.0
	2192400	0.1390	411.8398	30.8300	5.6160	0.0600	57.1000	0.0
	2192420	0.1244	533.2800	5.1500	5.5980	0.0	54.1000	0.0
	2193600	0.1208	316.7998	8.0900	7.0960	0.0	31.2000	1.0000
	2201110	0.1292	147.8400	29.5300	3.5320	1.1000	40.3000	0.0
	2201160	0.1254	158.4000	23.9800	3.4010	0.3000	46.5000	0.0
	2201830	0.1318	300.9600	23.1600	5.2880	1.5000	63.3000	0.0
	2202910	0.2197	137.2800	4.3700	3.8330	0.0	31.1000	0.0
	2202950	0.2027	95.0400	6.1000	4.3880	0.5000	48.7000	0.0
	2206200	0.1000	348.4797	5.4700	5.3110	0.0	30.0000	0.0
	2211450	0.0693	380.1599	13.3500	5.6570	0.8300	48.4000	5.0000
	2215280	0.1267	242.8800	11.4200	4.6610	0.3000	77.1000	0.0

Table D.2 . continued

SAMPLE	A	P	CC	E	RMAX	L	S	RRAT	W	SHAPE
2214610	3.2300	6.8200	1.0700	222.0000	94.0000	2.3700	19.8000	39.6500	1.3600	0.5800
2217250	0.3900	2.4400	1.1020	835.0000	145.0000	0.7200	146.0000	201.3900	0.5400	0.7500
2217400	2.6800	6.8200	1.1750	843.0000	184.0000	2.7200	71.0000	67.6500	0.9900	0.3600
2217560	0.8700	4.2400	1.2820	854.0000	160.0000	1.3700	62.0000	116.7900	0.6400	0.4600
2218100	1.9500	6.4600	1.3050	746.0000	126.0000	2.3500	43.0000	53.6200	0.8300	0.3500
2223700	2.1300	6.0800	1.1750	284.0000	129.0000	2.3200	36.7000	55.6000	0.9200	0.4000
2224200	16.1000	18.3500	1.2900	277.0000	205.0000	6.5200	15.5000	31.4400	2.4700	0.3800
2225330	9.5900	14.6200	1.3320	254.0000	140.0000	5.4800	19.0000	25.5500	1.7500	0.3200
2315980	1.2100	4.9400	1.2670	355.0000	64.0000	1.4700	33.6000	43.5400	0.8200	0.5600
2316220	1.6500	5.6500	1.2410	350.0000	35.0000	2.3900	17.9000	14.6400	0.6900	0.2900
2316260	4.1600	10.4700	1.4480	242.0000	29.0000	3.7300	6.1000	7.7700	1.1200	0.3000
2317710	0.8600	3.4700	1.0560	232.0000	52.0000	1.3800	30.8000	37.6800	0.6200	0.4500
2317760	8.5400	14.3200	1.3820	443.0000	124.0000	6.2100	15.7000	19.9700	1.3800	0.2200
2317765	0.9800	4.4900	1.2790	444.0000	78.0000	2.0500	26.0000	38.0500	0.4800	0.2300
2317770	6.4800	12.4800	1.3830	428.0000	133.0000	5.6500	18.0000	23.5400	1.1500	0.2000
2317775	1.1100	4.6200	1.2370	436.0000	72.0000	1.5900	29.4000	45.2800	0.7000	0.4400
2317780	0.6800	3.5200	1.2380	395.0000	65.0000	1.2700	39.8000	51.1800	0.5400	0.4200
2317795	6.2100	10.6600	1.2070	360.0000	125.0000	3.7700	19.1000	33.1600	1.6500	0.4400
2317845	1.6400	8.6900	1.9140	417.0000	92.0000	2.1600	29.0000	42.5900	0.7600	0.3500
2317905	4.2200	10.6800	1.4670	340.0000	102.0000	3.6900	21.6000	27.6400	1.1400	0.3100
2317910	2.0700	4.3600	9.8550	275.0000	70.0000	2.9400	19.5600	23.8100	0.7000	0.2400
2318015	1.3600	4.5900	1.1100	285.0000	45.0000	1.7400	23.2000	25.8600	0.7800	0.4500
2318020	0.2700	1.8400	0.9990	265.0000	41.0000	0.6100	50.4000	67.2100	0.4400	0.7300
2327350	1.8100	6.0200	1.2620	273.0000	97.0000	2.3800	28.5000	40.7600	0.7600	0.3200
2327400	3.7000	8.2800	1.2140	353.0000	88.0000	3.0800	12.7000	28.5700	1.2000	0.3900
2346193	3.3600	9.2400	1.4220	682.0000	202.0000	3.4500	27.8000	58.5500	0.9700	0.2800
2346210	6.6200	12.1600	1.3330	668.0000	264.0000	4.6000	32.8000	57.3900	1.4400	0.3100
2346217	2.8200	7.2700	1.2210	911.0000	385.0000	2.7300	51.3000	141.0300	1.0300	0.3800
2353520	3.7700	8.4000	1.2230	394.0000	162.0000	3.3700	30.4000	48.0700	1.1200	0.3300
2381100	2.3300	7.0800	1.3090	1610.0000	445.0000	3.0900	142.0000	144.0100	0.7500	0.2400
2381400	9.9900	15.1900	1.3560	1854.0000	1455.0000	6.1900	111.0000	235.0600	1.6100	0.2600
2381900	3.5200	9.4700	1.4240	1383.0000	710.0000	4.7500	125.0000	149.4700	0.7400	0.1600
2382200	3.0600	8.7100	1.4050	1035.0000	922.0000	2.8400	97.8000	324.6499	1.0800	0.3800
2382900	12.8000	21.8700	1.7200	1176.0000	1560.0000	7.6500	48.0000	203.9200	1.6700	0.2200
2383000	5.6100	11.0400	1.3150	921.0000	310.0000	3.0000	44.9000	103.3300	1.8700	0.6200
2387300	0.1700	1.7600	1.2040	715.0000	123.0000	0.6200	174.0000	198.3900	0.2700	0.4400
2387560	3.5600	7.9700	1.1920	899.0000	428.0000	2.9600	65.5000	144.5900	1.2000	0.4100
2387700	8.6300	17.0800	1.6400	1098.0000	1135.0000	6.7500	58.1000	168.1500	1.2800	0.1900
2387900	3.9200	9.1900	1.3260	1116.0000	825.0000	3.4100	62.4000	241.9400	1.1200	0.3300
2388200	6.0400	10.4200	1.1960	1012.0000	835.0000	3.2200	65.0000	259.3201	1.8800	0.5800
2388400	3.0000	8.8100	1.4350	836.0000	550.0000	3.2800	93.0000	167.6800	0.9100	0.2800
2397750	6.3400	12.4600	1.3960	1304.0000	1313.0000	4.4700	63.4000	293.7400	1.4200	0.3200
3566660	4.4400	10.0200	1.3410	959.0000	240.0000	3.4400	19.6000	69.7700	1.2900	0.3800
3566687	3.3600	8.6700	1.3340	957.0000	390.0000	2.8000	41.7000	139.2900	1.2000	0.4300
ILL: 3338100	2.2000	7.9900	1.5200	671.0000	70.0000	3.4000	15.8100	20.5900	0.6500	0.1900
3344250	0.0810	1.3500	1.3380	506.0000	10.0000	0.3800	10.5100	26.3200	0.2100	0.5600
3380300	0.0780	1.2900	1.3030	534.0000	35.0000	0.4000	98.7400	86.8500	0.1900	0.4800
3380450	0.4300	3.1400	1.3510	560.0000	117.0000	1.1100	87.6500	105.4100	0.3900	0.3500
3381600	0.1600	1.8600	1.3120	481.0000	70.0000	0.6200	89.7600	112.9000	0.2600	0.4200
3382025	0.5200	3.0500	1.1930	597.0000	135.0000	1.1300	75.5000	119.4700	0.4600	0.4100

Table D.2 , continued

SAMPLE	OVL	OVS	LCHAN	CO	ST	F	I
2216610	0.1142	179.5200	6.5000	2.0120	0.2000	54.3000	0.0
2217250	0.1206	343.2000	3.7900	9.7180	0.0	29.2000	0.0
2217400	0.1716	501.6001	15.1900	5.6680	0.3700	50.5000	0.0
2217660	0.1754	337.9199	4.8900	5.6210	0.0	38.5000	0.0
2218100	0.1350	253.4400	9.4300	4.8360	0.0100	29.3000	0.0
2223700	0.0951	258.7200	13.1100	6.1550	0.5000	71.4000	0.0
2224200	0.0989	254.0000	51.8900	3.2230	0.4000	72.5000	0.0
2225330	0.1307	253.4400	42.8600	4.4740	1.5000	60.0000	0.0
2315980	0.1928	132.0000	3.5600	2.9420	2.4000	43.1000	0.0
2316720	0.1231	264.0000	4.7500	2.8790	0.9000	47.8000	0.0
2316260	0.2977	26.4000	8.7700	2.1080	0.2000	90.8000	0.0
2317710	0.2136	100.3200	1.9700	2.2910	0.2000	68.1000	0.0
2317760	0.1777	158.4000	31.6700	3.7080	0.0	56.0000	0.0
2317765	0.1504	190.0800	4.2000	4.2860	0.0	51.0000	0.0
2317770	0.1500	221.7600	22.7700	3.5140	0.1000	59.9000	0.0
2317775	0.1646	174.2400	4.3900	3.9550	0.0	55.8000	0.0
2317780	0.1792	153.1200	2.4600	3.6180	0.6000	17.0000	0.0
2317795	0.1254	174.2400	23.8600	3.8420	1.0000	33.3000	0.0
2317945	0.1566	153.1200	7.9500	4.8480	0.0	36.8000	0.0
2317905	0.1689	163.6800	13.6400	3.2320	0.7000	27.9000	0.0
2317910	0.1231	264.0000	7.4200	3.5850	0.1000	24.8000	0.0
2318015	0.1326	264.0000	4.6500	3.4490	0.0	38.2000	0.0
2319020	0.1379	168.9600	1.2500	4.6300	0.0	47.3000	0.0
2327350	0.1894	195.3600	5.9700	3.2980	0.3000	53.0000	0.0
2327400	0.2470	147.8400	11.3400	3.0650	1.5000	29.3000	0.0
2346193	0.0928	480.4800	25.2500	7.5150	0.2400	90.4000	0.0
2346210	0.0850	496.3198	40.1100	6.0590	0.6200	81.8000	0.0
2346217	0.1053	644.1597	15.9500	5.6560	0.0	60.0000	0.0
2350520	0.1542	269.2798	6.2500	1.6580	0.1000	73.1000	0.0
2381100	0.0670	1003.2000	24.3900	10.4690	0.0	89.7000	0.0
2381600	0.0754	1219.6799	65.5300	6.5600	0.0	97.1000	0.0
2381900	0.0697	855.3599	30.5100	8.6690	0.0	99.0000	0.0
2382300	0.0667	1589.2798	30.0200	9.8100	0.2700	92.8000	0.0
2382900	0.0869	1341.1199	78.4700	6.1300	0.0	91.0000	0.0
2383000	0.0773	902.8799	30.4900	5.4350	0.0	69.0000	0.0
2387300	0.0839	422.3599	1.7000	10.0000	2.6000	55.3000	0.0
2387560	0.0886	828.9600	18.9800	5.3310	0.0500	81.3000	0.0
2387700	0.0811	1642.0798	50.9500	5.9040	0.0500	94.6000	0.0
2387800	0.1720	1256.6396	19.8500	5.1960	0.2300	93.1000	0.0
2398200	0.0973	1251.3599	36.3800	6.0230	0.0	78.3000	0.0
2398400	0.1059	876.4800	18.3300	6.1100	0.8400	64.1000	0.0
2357750	0.2034	1177.4399	30.8900	4.8720	0.0	78.8000	0.0
3566660	0.0562	797.2800	22.9700	5.1730	0.1000	58.8000	0.0
3566687	0.1095	681.1199	21.1200	6.2860	0.1900	59.2000	0.0
ILL 3338100	0.1098	63.3600	6.2500	2.8410	0.0	0.0	0.0
3344250	0.1034	47.5200	0.8000	9.8770	0.0	0.0	0.0
3380300	0.0568	153.1200	0.7000	8.9740	0.0	29.3900	0.0
3380450	0.0941	464.6399	4.8900	11.3720	0.0	17.5100	0.0
3381600	0.0456	528.0000	2.0100	12.5620	4.0000	43.0000	0.0
3382025	0.0581	438.2400	4.9200	9.4620	0.0	33.0000	0.0

Table D.2 , continued

SAMPLE	A	P	CC	E	RMAX	L	S	RRAT	W	SHAPE
5418900	0.8600	4.0500	1.2440	1044.0000	305.0000	1.5100	157.8700	201.9900	0.5700	0.3800
5437600	2.2100	7.3700	1.3990	822.0000	122.0000	2.5300	40.2600	48.2200	0.8700	0.3500
5438650	1.6700	5.7600	1.2570	945.0000	90.0000	2.6000	28.7200	34.6200	0.6400	0.2500
5439550	1.7100	5.6500	1.2620	799.0000	137.0000	2.2200	53.7500	61.7100	0.7700	0.3500
5448050	0.2200	1.8200	1.0950	772.0000	42.0000	0.7600	67.0600	55.4100	0.2900	0.3800
5465750	0.2600	3.5000	1.9360	752.0000	43.0000	1.6700	28.7800	25.7500	0.1600	0.0900
5493200	1.4500	4.9400	1.1570	619.0000	67.0000	1.8200	34.4800	36.8100	0.8000	0.4400
5502120	0.7800	4.1000	1.3100	738.0000	125.0000	1.2000	78.6700	104.1700	0.6500	0.5400
5527050	0.8000	4.6200	1.4570	786.0000	70.0000	1.9300	29.6700	36.2700	0.4100	0.2100
5536265	8.8400	5.9100	0.5610	654.0000	13.0000	7.0500	8.7100	1.8400	1.2500	0.1800
5541799	4.5200	11.4000	1.5130	614.0000	29.0000	4.8900	6.5500	5.9300	0.9200	0.1900
5551800	0.4500	2.7500	1.1560	772.0000	107.0000	1.0200	87.1200	104.9000	0.4400	0.4300
5554600	0.1600	1.6000	1.1280	738.0000	40.0000	0.7900	60.7200	50.6300	0.2000	0.2600
5555400	0.1400	2.0000	1.5080	661.0000	45.0000	0.9000	50.3700	50.0000	0.1600	0.1700
5557100	0.3300	3.5500	1.7430	807.0000	185.0000	1.6500	97.1500	112.1200	0.2000	0.1200
5558050	0.0300	0.8300	1.3520	664.0000	58.0000	0.3000	228.6200	191.4200	0.1000	0.3300
5559075	0.2200	2.7700	1.3650	644.0000	133.0000	0.9500	139.3900	156.1000	0.2600	0.3000
5566003	6.3000	10.3000	1.2140	742.0000	42.0000	3.1100	11.1400	13.5000	2.0300	0.6500
5572100	0.1000	1.0000	0.8920	688.0000	10.0000	0.3700	34.1100	27.2500	0.2700	0.7400
5577520	1.2700	4.3500	1.0990	593.0000	31.0000	1.8400	18.0700	16.8500	0.6900	0.3800
5577700	1.5000	5.8900	1.3570	587.0000	57.0000	1.3600	40.1300	41.9100	1.1000	0.8100
5586500	2.3000	7.7500	1.4420	644.0000	68.0000	3.3000	24.2900	20.6100	0.7000	0.2100
5587850	0.4500	2.6700	1.1230	512.0000	70.0000	0.9200	42.5000	76.2500	0.4900	0.5300
5591500	8.0500	12.3000	1.2230	664.0000	30.0000	4.2000	5.2300	7.1400	1.9200	0.4600
5594200	1.9000	5.6000	1.1460	530.0000	79.0000	2.8800	17.1600	27.4300	0.6600	0.2300
5595550	0.6500	3.5200	1.2320	603.0000	140.0000	1.6900	62.7800	82.8400	0.3800	0.2300
5596100	1.0300	4.9000	1.3620	479.0000	107.0000	1.7800	39.0200	60.1100	0.5800	0.3300
5599640	0.4300	2.9500	1.2690	510.0000	190.0000	1.1900	111.9400	159.6600	0.3600	0.3000
MISS 2429980	2.0500	6.6300	1.3060	525.0000	175.0000	2.8000	42.3000	62.5000	0.7300	0.2600
2435300	0.1400	1.5700	1.1840	358.0000	87.0000	0.5700	127.0000	152.6300	0.2500	0.4300
2435400	0.7500	3.9000	1.2700	361.0000	110.0000	1.6800	63.4000	65.4800	0.4500	0.2700
2437550	0.5400	3.5800	1.3740	414.0000	120.0000	1.4300	79.2000	83.9200	0.3800	0.2600
2440020	0.7200	4.4000	1.4630	296.0000	65.0000	1.2800	47.5000	50.7800	0.5600	0.4400
2441220	0.4400	3.0000	1.2760	284.0000	55.0000	1.1000	42.2000	50.0000	0.4000	0.3600
2447740	0.6000	3.6200	1.3180	342.0000	60.0000	1.8600	47.5000	32.2600	0.3200	0.1700
2475220	0.7200	1.8600	1.1190	507.0000	120.0000	0.6600	116.0000	181.8200	0.3300	0.5100
2477090	0.4500	3.3900	1.4260	482.0000	205.0000	1.1000	148.0000	186.3600	0.4100	0.3700
2478500	0.6900	3.7500	1.2870	297.0000	85.0000	1.1900	47.5000	71.4300	0.5800	0.4900
2479165	0.2200	1.9500	1.1730	153.0000	60.0000	0.6800	121.0000	86.2400	0.3200	0.4800
2481505	2.2900	6.3000	1.1740	172.0000	150.0000	2.3500	42.2000	63.8300	0.9700	0.4100
2485780	0.4500	2.6500	1.1140	334.0000	80.0000	1.0000	42.2000	80.0000	0.4500	0.4500
2485930	1.0900	3.4800	0.9400	356.0000	92.0000	1.4500	42.2000	63.4500	0.7500	0.5200
2487670	0.9100	4.0000	1.1830	484.0000	125.0000	1.1800	68.6000	105.9300	0.7700	0.6500
2487710	0.8800	4.2600	1.2810	325.0000	130.0000	2.0400	42.2000	63.7300	0.4300	0.2100
2488550	0.3400	2.0800	1.0060	523.0000	75.0000	0.7400	95.0000	101.3500	0.4600	0.6200
2488680	0.2300	2.3500	1.3820	379.0000	105.0000	0.9200	63.4000	114.1300	0.2500	0.2700
2489030	0.9100	4.2200	1.2480	344.0000	120.0000	1.2300	63.4000	97.5600	0.7400	0.6000
2489160	1.2600	4.6200	1.1610	377.0000	85.0000	1.4000	68.6000	60.7100	0.9000	0.6400
7029252	1.2400	4.9000	1.2410	592.0000	170.0000	2.0200	58.1000	84.1600	0.6100	0.3000
7267200	0.2300	2.1000	1.2350	471.0000	90.0000	0.8200	121.0000	109.7600	0.2800	0.3400

Table D.2 , continued

SAMPLE	OVL	OVS	LCHAN	DO	ST	F	I
5418900	0.0890	728.6399	5.7200	6.6510	0.0	9.8200	0.0
5437600	0.0714	200.6400	10.4900	4.7470	0.0	2.0000	0.0
5438850	0.0996	137.2800	6.2900	3.7660	0.0	0.0	0.0
5439550	0.0597	242.9800	9.0900	5.3160	0.0	6.0000	0.0
5448050	0.0795	168.9600	1.9700	8.9550	0.0	0.0	0.0
5465750	0.1667	52.8000	1.6000	6.1540	0.0	0.0	0.0
5495700	0.1121	116.1600	12.6300	8.7100	0.0	5.2700	0.0
5502120	0.1225	242.9800	4.0500	5.1920	4.9800	14.9600	0.0
5527050	0.1195	153.1200	4.0000	5.0300	0.0	14.1100	0.0
5536265	0.2568	73.9200	4.1700	0.4720	1.8400	1.3800	5.0000
5541750	0.3646	15.8400	7.3500	1.6260	0.0	0.0	0.0
5551900	0.0892	216.4800	3.9400	8.7560	0.0	7.0000	0.0
5554600	0.0750	153.1200	1.1500	7.1870	0.0	0.0	0.0
5555400	0.0792	79.2000	0.7500	5.3570	0.0	0.0	0.0
5557100	0.0858	395.9999	2.7000	8.1820	0.0	0.0	0.0
5558050	0.0580	250.7200	0.5100	17.0000	0.0	0.0	0.0
5558075	0.0553	401.2798	2.2700	10.3180	0.0	0.0	0.0
5566000	0.1716	79.2000	14.3500	2.2780	0.0	0.6200	0.0
5572100	0.1070	47.5200	0.4000	4.0000	0.0	0.0	0.0
5577520	0.2205	26.4000	2.7800	2.1890	0.0	0.0	12.0000
5577700	0.1195	116.1600	7.9200	5.2800	0.3800	1.1300	0.0
5586500	0.1691	84.4800	6.6500	2.8910	0.0	5.1600	0.0
5587850	0.0756	353.7598	4.8500	10.7780	1.2700	12.6900	0.0
5591500	0.2055	58.0800	11.0000	1.3660	0.0	0.5000	5.0000
5594200	0.1458	58.0800	9.0000	4.7370	0.0	2.1200	0.0
5595550	0.1066	406.5601	4.4100	6.7850	3.0000	21.0000	5.0000
5596100	0.1292	179.5200	6.2000	6.0190	0.0	10.0000	0.0
5595640	0.0530	1372.7998	4.9200	11.4420	0.0	74.5800	0.0
MISS.2429980	0.0553	839.5198	8.0700	3.9370	0.0	90.0000	0.0
2435300	0.0606	469.9199	0.7600	5.4290	0.0	40.0000	0.0
2435400	0.0559	528.0000	2.4600	3.2800	0.0	82.0000	0.0
2437550	0.0903	417.1199	4.3900	8.1300	0.0	54.0000	0.0
2440320	0.1347	116.1600	1.6500	2.2920	0.0	1.0000	0.0
2441220	0.1292	147.8400	1.9000	4.3180	0.0	14.0000	0.0
2447340	0.0672	237.6000	3.0100	5.0170	0.0	82.0000	0.0
2415220	0.0574	591.3599	1.4000	6.3640	0.0	80.0000	0.0
2477090	0.0712	406.5601	2.1400	4.7560	0.0	73.0000	0.0
2478400	0.0564	411.8398	3.5200	5.1010	0.0	75.0000	0.0
2479165	0.0875	237.6000	0.5500	2.5000	0.0	71.0000	0.0
2481505	0.1125	332.6399	6.0000	2.6200	0.0	90.0000	0.0
2485780	0.0701	216.4800	1.3600	3.0220	0.0	20.0000	23.9000
2485900	0.0511	443.5198	9.6500	8.8530	0.0	83.0000	0.0
2487670	0.0593	411.8398	4.7200	5.1870	0.0	69.0000	0.0
2487710	0.0634	380.1599	4.3600	4.9550	0.0	65.0000	0.0
2488550	0.0581	485.7600	1.7600	5.1760	0.0	90.0000	0.0
2488680	0.0545	380.1599	1.9700	8.5650	0.0	67.0000	0.0
2489020	0.0578	390.7200	4.2400	4.6590	0.0	62.0000	0.0
2489160	0.0756	264.0000	4.6400	3.6830	0.0	25.0000	0.0
7029252	0.0684	797.2800	3.2000	2.5810	0.0	90.0000	0.0
7267200	0.0767	475.1597	1.1500	5.0000	0.0	83.0000	0.0

Table D.2 , continued

SAMPLE	A	P	CC	E	RMAX	L	S	RRAT	W	SHAPE
7277550	0.2900	2.6000	1.3620	365.0000	85.0000	0.6100	143.0000	139.3400	0.4800	0.7800
7282300	0.5000	2.3000	0.9180	319.0000	60.0000	1.0100	58.1000	59.4100	0.5000	0.4900
7285700	1.6400	5.1500	1.1340	342.0000	110.0000	1.6200	47.5000	67.9000	1.0100	0.6200
7287140	0.2600	3.2000	1.7700	125.0000	9.0000	0.6900	26.4000	13.0400	0.3800	0.5500
7287520	1.4900	5.1500	1.1900	288.0000	160.0000	2.6300	58.1000	60.8400	0.5700	0.2200
7288558	0.1800	1.9000	1.2630	121.0000	10.0000	0.4700	31.7000	21.2800	0.3800	0.8100
7289640	0.2600	2.1000	1.1620	303.0000	40.0000	0.7400	68.6000	54.0500	0.3500	0.4700
7290220	0.2000	1.8900	1.1920	478.0000	70.0000	0.5600	68.6000	125.0000	0.3600	0.6400
7290525	1.3600	5.4400	1.3160	308.0000	132.0000	2.3900	37.0000	55.2300	0.5700	0.2400
7290910	2.5900	6.9500	1.2160	179.0000	150.0000	3.9200	26.4000	38.2700	0.6600	0.1700
7294400	0.2200	3.2500	1.9550	170.0000	235.0000	1.1400	153.0000	206.1400	0.1900	0.1700
7373550	0.2100	1.8500	1.1390	364.0000	40.0000	0.6500	58.1000	61.5400	0.3200	0.5000
7375235	2.7100	6.7400	1.1550	410.0000	100.0000	2.5100	37.0000	39.8400	1.0800	0.4300
7376665	0.3800	2.6700	1.2220	408.0000	82.0000	1.1700	63.4000	70.0900	0.3200	0.2800
7376760	0.8000	3.8500	1.2140	381.0000	65.0000	1.3300	47.5000	48.8700	0.6000	0.4500
MO 5497700	2.3800	6.4200	1.1740	817.0000	110.0000	2.2500	43.2000	48.8900	1.0600	0.4700
5502700	0.7100	3.2000	1.0710	760.0000	75.0000	1.2200	76.1000	61.4800	0.5800	0.4800
5503000	2.6400	6.3600	1.1040	754.0000	75.0000	2.3400	32.3000	32.0500	1.1300	0.4800
6815550	0.4900	2.9000	1.1670	1139.0000	90.0000	1.2000	61.1000	75.0000	0.4100	0.3400
6816000	4.9000	9.1000	1.1600	1093.0000	195.0000	3.3000	42.3000	59.0900	1.4800	0.4500
6870030	6.0600	12.3500	1.4150	1160.0000	135.0000	5.8000	19.5000	23.2800	1.0400	0.1800
6857700	1.4400	4.3500	1.0230	818.0000	205.0000	1.6700	120.0000	122.7500	0.8600	0.5200
6902520	2.5100	7.9500	1.4160	955.0000	165.0000	3.5600	27.0000	46.3500	0.7100	0.2000
6902400	1.0400	4.4900	1.2420	853.0000	116.0000	1.8400	49.3000	63.0400	0.5700	0.3100
6907200	1.6500	5.6200	1.2340	835.0000	102.0000	1.8700	46.4000	54.5500	0.6800	0.4700
6908300	0.9700	4.4300	1.2690	859.0000	145.0000	1.5600	69.2000	92.9500	0.6200	0.4000
6909700	0.4900	3.5800	1.4430	805.0000	120.0000	1.3800	78.4000	86.9600	0.3600	0.2600
6910250	0.5500	3.0000	1.1410	770.0000	110.0000	0.8200	119.0000	134.1500	0.6700	0.8200
6918700	1.3000	4.7900	1.1850	1192.0000	220.0000	2.0500	94.2000	107.3200	0.6300	0.3100
6919200	0.1400	1.7600	1.3270	850.0000	85.0000	0.5800	149.0000	146.5500	0.2400	0.4200
6921740	1.1500	4.5500	1.1970	873.0000	152.0000	1.7300	70.6000	87.8600	0.6600	0.3800
6925300	1.4800	4.9300	1.1430	1080.0000	190.0000	1.5000	84.1000	126.6700	0.9900	0.6600
6927100	0.5400	3.3000	1.2670	790.0000	90.0000	1.3500	70.2000	66.6700	0.4000	0.3000
6931500	6.4100	10.7600	1.1990	1013.0000	390.0000	3.4500	65.6000	113.0400	1.8600	0.5400
6935800	0.8100	3.6000	1.1280	675.0000	160.0000	1.1800	79.5000	135.5900	0.6900	0.5800
7011200	0.8900	3.4000	1.0170	1262.0000	145.0000	1.4500	106.0000	100.0000	0.6100	0.4200
7011500	0.6200	3.3500	1.2000	1120.0000	160.0000	1.2000	82.0000	133.3300	0.5200	0.4300
7015500	0.2200	2.1400	1.7870	1192.0000	52.0000	0.6500	41.1000	80.0000	0.3400	0.5200
7017500	3.3500	9.8300	1.5150	962.0000	310.0000	4.3500	48.5000	71.2600	0.7700	0.1800
7064300	1.7200	5.7500	1.2370	1307.0000	195.0000	2.3500	68.1000	82.9800	0.7300	0.3100
7064500	8.3600	9.8000	0.9560	1384.0000	295.0000	4.0000	53.3000	73.7500	2.0900	0.5200
7185500	3.8600	8.9800	1.2890	1272.0000	152.0000	3.0000	41.3000	50.6700	1.2900	0.4300
TENN 3313600	0.9500	4.0500	1.1720	811.0000	140.0000	1.5500	73.9200	90.3200	0.6100	0.4000
3313620	3.0300	9.0900	1.4730	899.0000	200.0000	3.1200	52.8000	64.1000	0.9700	0.3100
3418900	1.5200	4.9200	1.1260	1920.0000	360.0000	1.8800	182.2700	191.4900	0.8100	0.4300
3420360	2.2800	6.3300	1.1830	1101.0000	94.0000	2.4600	35.3800	38.2100	0.9300	0.3800
3420380	1.0300	4.3000	1.1950	1099.0000	70.0000	1.3900	46.4600	50.3600	0.7400	0.5300
3420400	7.3000	12.6500	1.3210	1104.0000	240.0000	4.0500	30.6200	59.2600	1.8000	0.4500
3430400	12.0000	16.4400	1.3390	812.0000	560.0000	4.3400	30.5800	129.0300	2.7600	0.6400
3431520	4.1300	9.5100	1.3200	741.0000	360.0000	3.0100	69.2600	119.6000	1.3700	0.4600

Table D.2 , continued

	SAMPLE	OVL	OVS	LCHAN	DO	ST	F	I
	7277550	0.1133	274.5598	0.9500	3.2760	0.0	14.0000	0.0
	7282300	0.1250	237.6000	1.3000	2.6000	0.0	85.0000	0.0
	7285700	0.0778	475.1997	7.9500	4.8480	0.0	72.0000	0.0
	7287140	0.1250	26.4000	1.8000	6.9230	0.0	1.0000	0.0
	7287520	0.0985	464.6399	5.7500	3.8590	0.0	81.0000	0.0
	7288568	0.0545	63.3600	1.0500	5.8330	0.0	1.0000	0.0
	7289640	0.1091	205.9200	1.4000	5.3850	0.0	5.0000	0.0
	7290720	0.0504	337.9199	1.5900	7.9500	0.0	39.0000	0.0
	7290525	0.0583	422.3999	5.8900	4.3310	0.0	67.0000	0.0
	7290910	0.0741	480.4800	8.8600	3.4210	0.0	26.0000	20.0000
	7294400	0.0845	791.9598	4.0000	18.1820	0.0	95.0000	0.0
	7373550	0.0875	179.5200	1.2000	5.7140	0.0	14.0000	0.0
	7375235	0.0936	248.1600	9.2000	3.3950	0.0	34.0000	0.0
	7376665	0.1131	211.2000	2.3000	6.0530	0.0	21.0000	0.0
	7376760	0.1333	184.8000	3.2000	4.0000	0.0	64.0000	0.0
MO	5497700	0.0595	300.7600	16.7200	7.0250	2.0000	3.3000	0.0
	5502700	0.0648	242.8800	5.4200	7.6340	0.3000	12.2000	0.0
	5509000	0.0758	174.2400	10.6600	4.0380	0.4000	6.8000	0.0
	6815550	0.1083	221.7600	3.6500	7.4490	0.0	0.0	0.0
	6816000	0.1229	306.2400	20.6000	4.2040	4.0000	5.0000	0.0
	6820000	0.1059	227.0400	24.9500	4.1170	0.0	1.0000	0.0
	6897700	0.1167	290.3999	9.2000	6.3890	0.0	7.5000	0.0
	6902500	0.0616	406.5601	17.7300	7.0640	0.4000	4.4000	0.0
	6902800	0.0568	322.0798	7.5400	7.2500	0.1000	1.0000	0.0
	6907200	0.0784	195.3600	7.4100	4.4910	0.0	0.2000	0.0
	6908300	0.0604	390.7200	6.8400	7.0520	0.0900	8.0000	0.0
	6909700	0.0741	216.4800	2.9900	6.1020	0.0	3.0000	0.0
	6910250	0.0875	322.0798	3.7500	6.8180	0.0	10.5000	0.0
	6918700	0.0570	549.1156	7.5800	5.8310	0.0	86.0000	0.0
	6919200	0.0788	322.0798	1.0400	7.4290	0.0	0.0	0.0
	6921740	0.0540	438.2400	9.6500	8.3910	0.0	10.0000	0.0
	6925300	0.0820	448.7998	7.0500	4.7640	0.0	14.5000	0.0
	6927100	0.1133	295.6799	2.8500	5.2780	0.0	0.0	0.0
	6931500	0.0754	723.3601	28.3300	4.4200	0.8000	35.2000	0.0
	6935900	0.0606	332.6399	5.2100	6.4320	0.0	7.5000	0.0
	7011200	0.0966	337.9199	3.9500	4.4380	0.0	59.4000	0.0
	7011500	0.0553	406.5601	2.9500	4.7580	2.0000	3.7000	0.0
	7015500	0.1085	132.0600	1.0600	4.8180	1.0000	22.2000	0.0
	7017500	0.0769	343.2000	20.4500	6.1040	0.0100	17.3000	0.0
	7064300	0.1227	485.7600	10.2500	5.9590	0.0	65.2000	0.0
	7064500	0.1059	390.7200	35.2000	4.2110	0.1000	51.6000	0.0
	7185500	0.0816	264.0000	20.6400	5.3470	0.0	11.0000	0.0
TENN	3313600	0.0811	427.6797	6.5900	6.9370	0.0	22.5000	0.0
	3313620	0.0871	512.1599	17.1200	5.6500	0.0	35.1000	0.0
	3418500	0.0551	892.3201	9.3900	6.1780	0.0	89.5000	0.0
	3420360	0.0902	190.0800	9.3900	4.1180	0.0500	32.7000	0.0
	3420380	0.0894	147.8400	6.4000	6.2140	0.2500	44.8000	0.0
	3420400	0.1019	264.0090	35.9300	4.9220	0.1500	29.7000	0.0
	3430400	0.0864	670.5598	48.9800	4.0820	0.1200	62.2000	0.0
	3431520	0.0790	1715.9998	25.2300	6.1090	0.0900	72.0000	0.0

Table D.2 , continued

SAMPLE	A	P	CC	E	RMAX	L	S	RRAT	W	SHAPE
3431580	13.3000	16.9700	1.3130	667.0000	400.0000	4.5000	46.7000	88.8900	2.9600	0.6600
3431600	51.6000	32.8400	1.2900	641.0000	510.0000	21.4900	11.1300	23.7300	2.4000	0.1100
3431650	2.6600	7.1600	1.2380	747.0000	442.0000	2.3800	83.2600	185.7100	1.1200	0.4700
3435020	9.3200	13.8600	1.2810	882.0000	225.0000	4.0000	46.4600	56.2500	2.3300	0.5600
3435030	15.1000	18.5600	1.3470	812.0000	273.0000	6.7000	27.9800	40.7500	2.2500	0.3400
3435530	3.5000	8.4100	1.2680	853.0000	210.0000	3.5200	51.7400	59.6600	0.9900	0.2800
3461200	10.2000	14.3900	1.2710	3698.0000	5260.0000	4.4000	484.8501	195.4500	2.3200	0.5300
3469110	2.1800	6.9900	1.3360	3201.0000	3275.0000	3.0500	649.4399	73.7700	0.7100	0.2300
3486775	4.3800	9.3600	1.1950	1765.0000	890.0000	3.8700	124.8300	229.9700	1.2600	0.3300
3519610	2.1000	7.6500	1.4890	1054.0000	242.0000	2.2200	63.3600	109.0100	0.9500	0.4300
3519630	1.4700	5.8000	1.3490	995.0000	230.0000	1.1900	100.3200	193.2800	1.2400	1.0400
3519640	16.0000	18.1400	1.2790	1053.0000	284.0000	8.7900	17.4200	32.3100	1.8200	0.2100
3519650	3.6500	9.0900	1.3420	977.0000	260.0000	4.0700	29.5700	63.8300	0.9000	0.2200
3535140	1.2300	4.6900	1.1930	1282.0000	460.0000	1.7200	52.8000	267.4399	0.7200	0.4200
3535160	14.1000	21.0100	1.5780	1264.0000	530.0000	6.7800	15.8400	78.1700	2.0800	0.3100
3535180	3.2300	9.7200	1.5260	1273.0000	480.0000	4.5000	58.0800	104.8000	0.7100	0.1500
3538900	3.8000	8.6700	1.2550	1884.0000	252.0000	3.6700	45.4100	68.6600	1.0400	0.2800
3539100	1.1000	4.7000	1.2640	1880.0000	147.0000	1.6600	40.1300	88.5500	0.6600	0.4000
3597350	4.9900	12.4200	1.5680	1091.0000	440.0000	4.2000	49.6300	104.7600	1.1900	0.2600
3597400	9.5900	14.3600	1.3080	1097.0000	465.0000	6.0800	31.6800	76.4800	1.5800	0.2600
3597450	0.7300	3.9900	1.3170	1087.0000	360.0000	1.7000	132.0000	211.7600	0.4300	0.2500
3597500	16.3000	18.5600	1.2970	1064.0000	482.0000	8.3000	25.7100	58.0700	1.9600	0.2400
3597550	1.8600	6.0000	1.2410	1035.0000	370.0000	4.0200	58.0800	92.0400	0.4600	0.1200
3604070	0.5100	2.8400	1.1220	914.0000	230.0000	0.8700	200.4800	264.3701	0.5900	0.6700
3604080	1.5200	5.6100	1.2840	880.0000	270.0000	2.1600	105.6000	125.0000	0.7000	0.3300
3604090	6.0200	9.4700	1.0890	851.0000	320.0000	3.1400	73.9200	101.9100	1.9200	0.6100
3604100	10.1000	12.8000	1.1360	821.0000	385.0000	5.2300	49.6300	73.6100	1.9300	0.3700
7028935	1.0800	4.4300	1.2030	507.0000	117.0000	1.8000	52.8000	65.0000	0.6000	0.3300

Table D.2 , continued

SAMPLE	OVL	OVS	LCHAN	DD	ST	F	I
3431580	0.0977	1077.1199	49.0500	3.6980	0.3400	20.0000	0.0
3431600	0.1061	1166.8799	211.7400	4.1030	0.0700	35.6000	0.0
3431650	0.0860	1372.7598	15.6400	5.8800	0.1800	15.0000	0.0
3435020	0.0769	623.0398	42.2300	4.5310	0.0	22.0000	0.0
3435030	0.0828	633.5599	64.9600	4.3020	0.0	13.3000	0.0
3435600	0.0973	385.4399	13.3700	3.8200	0.1300	10.6000	0.0
3461200	0.0788	2291.5200	47.8800	4.6940	0.0	95.0000	0.0
3469110	0.0558	2658.0798	18.3700	8.4270	0.0	96.2000	0.0
3486725	0.0633	1219.6799	18.0700	3.7030	0.0	34.5000	0.0
3519610	0.0955	612.4800	11.1700	5.3190	0.0	27.3000	0.0
3519630	0.0705	501.6001	6.4800	4.4080	4.1600	37.5000	0.0
3519640	0.0958	649.4399	48.8600	3.0540	0.0	3.7000	0.0
3519650	0.0720	712.7598	12.9500	3.5490	0.0	32.4000	0.0
3535140	0.0691	1261.9199	3.4600	2.8130	0.0	33.3000	0.0
3535160	0.0727	997.9199	32.1800	2.2820	0.0	41.4000	0.0
3535180	0.0678	744.4797	10.2900	3.1860	0.2700	44.7000	0.0
3538700	0.0830	528.0000	17.2700	4.5450	1.0500	86.7000	0.0
3539150	0.0746	411.8398	7.9200	7.2000	0.0	67.3000	0.0
3597300	0.1261	1267.2000	21.7800	4.3650	0.0	41.0000	0.0
3597400	0.1055	1246.0798	41.8000	4.3590	0.0	46.7000	0.0
3597450	0.0731	1341.1199	3.7900	5.1920	0.0	31.2000	0.0
3597500	0.0926	1330.5598	64.5300	3.9590	0.0	33.3000	0.0
3597550	0.0989	971.5200	9.5600	5.1400	0.1800	36.7000	0.0
3604070	0.0659	807.8398	5.1500	10.0980	0.0	92.5000	0.0
3604080	0.0720	1003.2000	11.2900	7.4280	0.0	97.4000	0.0
3604090	0.0714	1129.9199	44.9200	7.4620	0.0	95.9000	0.0
3604100	0.0833	1151.0398	73.7000	7.2970	0.0	99.3000	0.0
7028935	0.0710	295.6799	6.7400	6.2410	0.0	4.4000	0.0

Table D.3 Estimated Percent of Total Drainage Area Covered by Soils of a Particular Class for Sites in Study

	SAMPLE	NO NAME	SAND	LOAMYSD	SANDYLM	LOAM	SILTLOAM	SILT	SDCLYLM	CLAYLOAM	SYCLYLOM	SANDYCLY	SILTYCLY	CLAY
ALA	2342200	0.0	0.0	0.0	64.00	8.00	8.00	0.0	0.0	20.00	0.0	0.0	0.0	0.0
	2343700	4.00	36.00	0.0	60.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2362745	0.0	10.00	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2363055	0.0	70.00	5.00	25.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2365310	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2371200	5.00	65.00	0.0	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2372510	0.0	30.00	0.0	70.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2399800	4.00	0.0	0.0	4.00	80.00	4.00	0.0	0.0	8.00	0.0	0.0	0.0	0.0
	2400033	36.00	0.0	0.0	20.00	12.00	4.00	0.0	0.0	20.00	4.00	0.0	4.00	0.0
	2400690	40.00	0.0	0.0	0.0	8.00	32.00	0.0	0.0	0.0	8.00	0.0	12.00	0.0
	2407900	5.00	0.0	0.0	0.0	0.0	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2408340	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2410000	40.00	0.0	4.00	20.00	0.0	0.0	0.0	0.0	36.00	0.0	0.0	0.0	0.0
	2412120	56.00	0.0	0.0	12.00	32.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2413400	0.0	0.0	0.0	68.00	4.00	0.0	0.0	0.0	28.00	0.0	0.0	0.0	0.0
	2414800	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2417400	35.00	0.0	0.0	40.00	0.0	0.0	0.0	0.0	25.00	0.0	0.0	0.0	0.0
	2421300	0.0	5.00	5.00	85.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.00
	2427513	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00
	2437800	10.00	0.0	0.0	60.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.00
	2437900	5.00	0.0	0.0	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2449400	12.00	0.0	0.0	4.00	4.00	0.0	0.0	0.0	0.0	0.0	0.0	16.00	64.00
	2450200	0.0	0.0	0.0	32.00	4.00	60.00	0.0	0.0	0.0	4.00	0.0	0.0	0.0
	2451550	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2451750	0.0	0.0	0.0	85.00	5.00	5.00	0.0	0.0	0.0	5.00	0.0	0.0	0.0
	2453900	0.0	0.0	0.0	55.00	0.0	45.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2457600	0.0	0.0	0.0	40.00	10.00	50.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2465265	10.00	0.0	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2473026	68.00	0.0	4.00	24.00	4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2475593	15.00	25.00	30.00	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3574405	72.00	0.0	0.0	24.00	0.0	4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3585300	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GA	2195020	4.00	0.0	0.0	48.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.00
	2185037	0.0	0.0	0.0	20.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.00
	2191270	8.00	0.0	0.0	32.00	0.0	0.0	0.0	16.00	44.00	0.0	0.0	0.0	0.0
	2191280	5.00	0.0	0.0	50.00	0.0	0.0	0.0	45.00	0.0	0.0	0.0	0.0	0.0
	2191600	12.00	0.0	0.0	28.00	0.0	0.0	0.0	52.00	8.00	0.0	0.0	0.0	0.0
	2191750	8.00	0.0	0.0	52.00	0.0	0.0	0.0	40.00	0.0	0.0	0.0	0.0	0.0
	2192300	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2192400	0.0	0.0	0.0	92.00	0.0	0.0	0.0	0.0	8.00	0.0	0.0	0.0	0.0
	2192423	0.0	0.0	0.0	90.00	0.0	0.0	0.0	0.0	10.00	0.0	0.0	0.0	0.0
	2193600	0.0	0.0	0.0	45.00	0.0	0.0	0.0	0.0	55.00	0.0	0.0	0.0	0.0
	2201110	12.00	0.0	0.0	88.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2201160	20.00	0.0	4.00	76.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2201830	8.00	20.00	56.00	16.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2202910	0.0	0.0	20.00	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2202550	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2208200	12.00	0.0	8.00	48.00	0.0	0.0	0.0	0.0	32.00	0.0	0.0	0.0	0.0
	2211459	4.00	0.0	0.0	48.00	0.0	0.0	0.0	32.00	16.00	0.0	0.0	0.0	0.0
	2215200	12.00	0.0	80.00	8.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.3 , continued

SAMPLE	NO NAME	SAND	LOAMYSD	SANDYLM	LOAM	SILTLOAM	SILT	SDCLYLM	CLAYLOAM	SYCLYLOM	SANDYCLY	SILTYCLY	CLAY
2216610	20.00	0.0	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2217250	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0
2217400	0.0	0.0	0.0	60.00	0.0	0.0	0.0	0.0	40.00	0.0	0.0	0.0	0.0
2217460	0.0	0.0	0.0	10.00	0.0	0.0	0.0	0.0	90.00	0.0	0.0	0.0	0.0
2218100	8.00	0.0	0.0	64.00	0.0	0.0	0.0	28.00	0.0	0.0	0.0	0.0	0.0
2223700	0.0	35.00	0.0	65.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2224200	8.00	16.00	4.00	72.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2224335	0.0	4.00	12.00	84.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2315980	12.00	4.00	80.00	4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2316220	0.0	36.00	64.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2316260	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317710	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317760	4.00	0.0	0.0	96.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317765	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317770	0.0	4.00	0.0	96.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317775	0.0	10.00	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317780	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317785	0.0	0.0	60.00	40.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317945	20.00	0.0	0.0	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317925	0.0	0.0	52.00	48.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2317910	16.00	0.0	84.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2318015	25.00	0.0	75.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2318020	50.00	0.0	50.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2327350	8.00	0.0	12.00	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2323400	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2346193	8.00	0.0	0.0	80.00	0.0	0.0	0.0	0.0	12.00	0.0	0.0	0.0	0.0
2346210	8.00	0.0	0.0	32.00	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	0.0
2346217	8.00	0.0	0.0	16.00	0.0	0.0	0.0	0.0	68.00	0.0	0.0	0.0	4.00
2350520	0.0	25.00	0.0	75.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2381199	4.00	0.0	0.0	84.00	4.00	0.0	0.0	8.00	0.0	0.0	0.0	0.0	0.0
2381600	0.0	0.0	0.0	80.00	12.00	0.0	0.0	8.00	0.0	0.0	0.0	0.0	0.0
2381900	8.00	0.0	0.0	88.00	0.0	0.0	0.0	4.00	0.0	0.0	0.0	0.0	0.0
2382830	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2382930	0.0	0.0	0.0	16.00	64.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0	0.0
2383000	0.0	0.0	0.0	0.0	75.00	15.00	0.0	0.0	10.00	0.0	0.0	0.0	0.0
2387300	5.00	0.0	0.0	0.0	0.0	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2387560	0.0	0.0	0.0	0.0	65.00	5.00	0.0	0.0	30.00	0.0	0.0	0.0	0.0
2387700	36.00	8.00	0.0	32.00	4.00	20.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2387800	0.0	0.0	0.0	0.0	76.00	24.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2388200	0.0	0.0	0.0	0.0	60.00	30.00	0.0	0.0	10.00	0.0	0.0	0.0	0.0
2388400	0.0	0.0	0.0	0.0	60.00	16.00	0.0	0.0	24.00	0.0	0.0	0.0	0.0
2393750	44.00	0.0	0.0	0.0	28.00	0.0	0.0	0.0	28.00	0.0	0.0	0.0	0.0
3366560	0.0	0.0	0.0	36.00	0.0	64.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3366687	0.0	0.0	0.0	4.00	0.0	96.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ILL 3338100	0.0	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	40.00	0.0	0.0	0.0
3344750	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3330300	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3390450	0.0	0.0	0.0	0.0	30.00	70.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3341800	20.00	0.0	0.0	0.0	0.0	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3362025	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.3 , continued .

SAMPLE	NO NAME	SAND	LOAMYSD	SANDYLM	LOAM	SILTLOAM	SILT	SDCLYLM	CLAYLOAM	SYCLYLOM	SANDYCLY	SILTYCLY	CLAY
5418800	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5433400	0.0	0.0	0.0	0.0	60.00	40.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5438850	0.0	0.0	0.0	0.0	0.0	80.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0
5439550	0.0	0.0	0.0	0.0	20.00	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5448C50	15.00	0.0	0.0	0.0	5.00	75.00	0.0	0.0	0.0	5.00	0.0	0.0	0.0
5449750	0.0	0.0	0.0	0.0	0.0	80.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0
5495200	0.0	0.0	0.0	0.0	10.00	80.00	0.0	0.0	0.0	10.00	0.0	0.0	0.0
5502120	0.0	0.0	0.0	0.0	20.00	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5527053	0.0	0.0	0.0	0.0	0.0	10.00	0.0	0.0	0.0	50.00	0.0	40.00	0.0
5536265	5.00	5.00	10.00	0.0	15.00	20.00	0.0	0.0	0.0	45.00	0.0	0.0	0.0
5541750	0.0	0.0	0.0	0.0	0.0	15.00	0.0	0.0	0.0	85.00	0.0	0.0	0.0
5551800	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5554600	0.0	0.0	0.0	0.0	0.0	75.00	0.0	0.0	0.0	20.00	0.0	5.00	0.0
5555400	0.0	0.0	0.0	0.0	0.0	80.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0
5557100	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5558C50	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5558075	0.0	0.0	0.0	5.00	0.0	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5566000	0.0	0.0	0.0	0.0	0.0	50.00	0.0	0.0	0.0	50.00	0.0	0.0	0.0
5572100	0.0	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	40.00	0.0	0.0	0.0
5577523	0.0	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	40.00	0.0	0.0	0.0
5577700	0.0	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	40.00	0.0	0.0	0.0
5586500	0.0	0.0	0.0	0.0	0.0	90.00	0.0	0.0	0.0	10.00	0.0	0.0	0.0
5587850	0.0	0.0	0.0	5.00	0.0	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5591500	0.0	0.0	0.0	0.0	0.0	25.00	0.0	0.0	0.0	75.00	0.0	0.0	0.0
5594203	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5595550	30.00	0.0	0.0	0.0	0.0	70.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5596100	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5599640	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MISS 2425940	0.0	0.0	0.0	95.00	0.0	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2435300	25.00	0.0	0.0	10.00	5.00	0.0	0.0	0.0	0.0	15.00	0.0	45.00	0.0
2435400	25.00	0.0	0.0	75.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2437550	60.00	0.0	0.0	35.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2440020	0.0	0.0	0.0	0.0	0.0	5.00	0.0	0.0	0.0	40.00	0.0	30.00	25.00
2441220	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.00	0.0	40.00	0.0
2447340	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2475229	20.00	0.0	0.0	30.00	40.00	0.0	0.0	10.00	0.0	0.0	0.0	0.0	0.0
2477090	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00
2478400	10.00	0.0	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2479165	5.00	0.0	5.00	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2481505	40.00	0.0	0.0	60.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2485783	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2485030	0.0	0.0	0.0	10.00	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2487670	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2487710	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2488553	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2488680	15.00	0.0	0.0	45.00	0.0	40.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2488330	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2489160	10.00	0.0	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7075252	99.00	0.0	0.0	0.0	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7767203	60.00	0.0	0.0	0.0	0.0	40.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.3 , continued

SAMPLE	NO NAME	SAND	LOAMYSD	SANDYLM	LOAM	SILTLOAM	SILT	SDCLYLM	CLAYLOAM	SYCLYLOM	SANDYCLY	SILTYCLY	CLAY
7277550	65.00	0.0	0.0	0.0	0.0	35.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7282300	10.00	0.0	0.0	0.0	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7285760	12.00	0.0	0.0	0.0	0.0	88.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7287140	5.00	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	20.00	0.0	0.0	15.00
7287520	80.00	0.0	0.0	0.0	0.0	20.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7288568	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00
7288640	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7290220	60.00	0.0	0.0	0.0	0.0	40.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7290525	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7290910	16.00	0.0	0.0	0.0	0.0	84.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7294400	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7373550	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7375235	12.00	0.0	0.0	49.00	4.00	36.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7376665	0.0	0.0	0.0	40.00	0.0	60.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7376760	0.0	0.0	0.0	8.00	28.00	64.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 5457700	0.0	0.0	0.0	0.0	25.00	75.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5532700	0.0	0.0	0.0	0.0	25.00	65.00	0.0	0.0	0.0	10.00	0.0	0.0	0.0
5503000	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6815550	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6816000	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6820000	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6857700	0.0	0.0	0.0	0.0	20.00	64.00	0.0	0.0	0.0	0.0	0.0	16.00	0.0
6902503	0.0	0.0	0.0	0.0	80.00	20.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6902800	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6907200	0.0	0.0	0.0	0.0	4.00	96.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6908300	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6905700	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6910253	75.00	0.0	0.0	0.0	0.0	5.00	0.0	0.0	20.00	0.0	0.0	0.0	0.0
6918700	0.0	0.0	0.0	0.0	70.00	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6919239	0.0	0.0	0.0	0.0	0.0	40.00	0.0	0.0	60.00	0.0	0.0	0.0	0.0
6921743	0.0	0.0	0.0	0.0	24.00	56.00	0.0	0.0	0.0	4.00	0.0	16.00	0.0
6925390	5.00	0.0	0.0	0.0	45.00	15.00	0.0	0.0	0.0	35.00	0.0	0.0	0.0
6927103	0.0	0.0	0.0	5.00	0.0	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6931500	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6935800	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7011200	4.00	0.0	0.0	0.0	64.00	32.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7011500	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7015100	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7017500	0.0	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7064300	24.00	0.0	0.0	0.0	64.00	12.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7064503	0.0	0.0	0.0	0.0	96.00	4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7185500	0.0	0.0	0.0	0.0	5.00	95.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TENN 3213600	0.0	0.0	0.0	0.0	70.00	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3313670	0.0	0.0	0.0	0.0	70.00	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3418700	10.00	0.0	0.0	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3420360	0.0	0.0	0.0	0.0	0.0	95.00	0.0	0.0	0.0	5.00	0.0	0.0	0.0
3420380	0.0	0.0	0.0	0.0	0.0	80.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0
3420600	0.0	0.0	0.0	0.0	0.0	80.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0
3430400	48.00	0.0	0.0	0.0	0.0	28.00	0.0	0.0	0.0	20.00	0.0	4.00	0.0
3431520	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.3 . continued

SAMPLE	NO NAME	SAND	LOAMYSD	SANDYLM	LOAM	SILTLOAM	SILT	SDCLYLM	CLAYLOAM	SYCLYLOM	SANDYCLY	SILTYCLY	CLAY
3431580	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3431600	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3431650	0.0	0.0	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3435020	0.0	0.0	0.0	0.0	45.00	55.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3435030	0.0	0.0	0.0	0.0	40.00	60.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3435600	0.0	0.0	0.0	0.0	0.0	96.00	0.0	0.0	0.0	4.00	0.0	0.0	0.0
3461200	56.00	0.0	0.0	32.00	0.0	12.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3469110	8.00	0.0	0.0	16.00	0.0	4.00	72.00	0.0	0.0	0.0	0.0	0.0	0.0
3496225	0.0	0.0	0.0	4.00	48.00	36.00	0.0	0.0	0.0	12.00	0.0	0.0	0.0
3519610	0.0	0.0	0.0	0.0	0.0	15.00	0.0	0.0	0.0	85.00	0.0	0.0	0.0
3519630	0.0	0.0	0.0	0.0	0.0	20.00	0.0	0.0	0.0	75.00	0.0	5.00	0.0
3519640	0.0	0.0	0.0	0.0	0.0	24.00	0.0	0.0	0.0	68.00	0.0	8.00	0.0
3519650	0.0	0.0	0.0	0.0	0.0	25.00	0.0	0.0	0.0	50.00	0.0	25.00	0.0
3535140	5.00	0.0	0.0	35.00	20.00	35.00	0.0	0.0	0.0	5.00	0.0	0.0	0.0
3535160	8.00	0.0	0.0	20.00	0.0	52.00	0.0	0.0	0.0	20.00	0.0	0.0	0.0
3535180	15.00	0.0	0.0	0.0	20.00	60.00	0.0	0.0	0.0	5.00	0.0	0.0	0.0
3538700	0.0	0.0	0.0	72.00	28.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3535100	0.0	0.0	0.0	80.00	20.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3597300	44.00	0.0	0.0	0.0	0.0	44.00	0.0	0.0	0.0	12.00	0.0	0.0	0.0
3597400	48.00	0.0	0.0	0.0	0.0	52.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3597450	35.00	0.0	0.0	0.0	0.0	60.00	0.0	0.0	0.0	5.00	0.0	0.0	0.0
3597500	56.00	0.0	0.0	0.0	0.0	40.00	0.0	0.0	0.0	4.00	0.0	0.0	0.0
3597550	65.00	0.0	0.0	0.0	0.0	20.00	0.0	0.0	0.0	15.00	0.0	0.0	0.0
3604075	0.0	0.0	0.0	0.0	85.00	15.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3604090	0.0	0.0	0.0	0.0	96.00	4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3604050	0.0	0.0	0.0	0.0	84.00	16.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3604100	0.0	0.0	0.0	0.0	84.00	16.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7028935	0.0	0.0	0.0	0.0	20.00	80.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.4 Estimated Percent of Total Drainage Area Covered by Sand, Silt, Clay and Coarse Material for Sites in Study

SAMPLE	% SAND	% SILT	% CLAY	% COARSE
ALA 2342200	47.86	30.06	19.67	2.41
2343700	69.01	18.85	12.14	0.0
2362745	49.95	22.60	16.94	10.51
2363055	80.75	11.65	7.60	0.0
2365310	60.00	25.00	15.00	0.0
2371200	76.86	13.71	9.42	0.01
2372510	68.40	19.60	12.00	0.0
2399800	25.13	25.97	23.70	25.20
2400033	27.98	27.26	23.17	21.59
2400690	14.36	23.12	18.11	44.41
2407900	21.47	26.47	22.06	30.00
2408340	33.30	33.30	33.40	0.0
2410000	34.42	28.38	26.39	10.81
2412320	31.70	27.50	26.39	14.41
2412400	27.70	23.50	22.39	26.41
2414800	33.30	33.30	33.40	0.0
2417400	39.82	28.32	24.36	7.50
2421300	61.05	23.35	15.60	0.0
2427013	30.00	25.00	45.00	0.0
2437800	26.98	21.98	27.04	24.00
2437900	40.65	23.15	18.20	18.00
2449400	28.96	29.76	41.29	0.0
2450200	29.34	27.02	22.05	21.59
2451550	45.32	24.32	18.36	12.00
2451750	37.18	24.68	20.14	18.00
2452900	39.75	43.00	17.25	0.0
2462600	33.83	44.83	18.34	3.00
2465205	57.33	25.83	16.84	0.0
2471026	42.12	30.60	27.27	0.01
2479583	69.89	17.24	12.86	0.01
3574405	35.51	30.51	26.78	7.20
3585380	16.66	56.66	20.68	6.00
GA 2189020	44.53	25.33	30.14	0.0
2189030	36.00	25.00	39.00	0.0
2191270	39.94	29.50	26.96	3.60
2191280	54.16	24.06	21.77	0.01
2191400	46.15	25.39	24.86	3.60
2191750	52.40	24.40	27.01	1.19
2192300	60.00	25.00	15.00	0.0
2192400	57.76	25.80	16.44	0.0
2192420	57.20	26.00	16.80	0.0
2193600	44.60	30.50	24.90	0.0
2201110	56.80	26.00	17.21	0.0
2201160	55.58	26.06	18.36	0.0
2201830	76.34	13.66	9.99	0.01
2202710	64.60	22.00	13.40	0.0
2202950	60.00	25.00	15.00	0.0
2208200	49.68	28.00	22.33	0.0
2211459	49.78	25.90	23.11	1.21
2215280	75.20	14.00	10.81	0.0
2216610	73.06	14.66	12.28	0.0
2217250	32.00	35.00	33.00	0.0
2217400	48.80	29.00	22.20	0.0
2217660	34.80	34.00	31.20	0.00
2218100	55.06	24.82	20.11	0.01
2223700	69.80	18.70	11.50	0.0
2224200	63.26	22.18	14.55	0.01
2225330	63.88	22.48	13.64	0.0
2315980	76.32	13.29	10.41	0.0
2316220	84.80	8.92	6.28	0.0
2316260	83.00	10.00	7.00	0.0
2317710	83.00	10.00	7.00	0.0
2317760	58.93	25.33	15.74	0.0
2317765	60.00	25.00	15.00	0.0
2317770	61.12	24.28	14.60	0.0
2317775	62.80	23.20	14.00	0.0
2317780	60.00	25.00	15.00	0.0
2317795	73.80	16.00	10.20	0.0
2317845	54.66	26.66	18.68	0.0
2317905	71.96	17.20	10.84	0.0
2317910	75.05	13.73	11.22	0.0
2318015	70.57	15.82	13.60	0.01
2318020	58.15	21.65	20.20	0.0
2327350	60.62	23.86	15.51	0.01
2327400	60.00	25.00	15.00	0.0
2346193	54.50	26.86	18.63	0.01
2346210	41.06	31.66	27.27	0.01
2346217	31.48	32.12	30.39	6.01
2350520	67.00	20.50	12.50	0.0
2381100	33.34	24.74	21.53	20.39
2381600	41.98	24.06	19.55	14.41
2381900	43.18	24.98	19.83	12.01
2382800	22.64	26.64	23.13	27.59
2382900	34.98	33.18	22.25	9.59
2383000	24.99	32.29	23.71	19.51
2387300	20.81	35.81	22.38	21.00
2387560	26.53	29.68	25.79	18.00
2387700	27.20	30.80	21.59	20.41
2387800	21.31	33.31	22.58	22.80
2388200	21.68	36.98	23.34	18.00
2388400	24.06	32.78	25.16	18.00
2397750	16.94	17.78	17.29	47.99
3566660	34.19	35.59	19.42	10.80
3566687	22.78	33.38	22.25	21.59
ILL 3338100	15.00	59.80	25.20	0.00
3344250	15.00	65.00	20.00	0.00
3380300	15.00	65.00	20.00	0.00
3380450	23.70	57.20	19.10	0.0
3381600	18.66	58.66	22.68	0.0
3382025	15.00	65.00	20.00	0.00

Table D.4 , continued

SAMPLE	% SAND	% SILT	% CLAY	% COARSE
5418800	15.00	65.00	20.00	0.00
5437600	32.40	49.40	18.20	0.0
5438850	15.00	62.40	22.60	0.0
5439550	20.80	59.80	19.40	0.0
5448050	19.19	58.29	22.51	0.01
5469750	15.00	62.40	22.60	0.0
5495200	17.90	61.10	21.00	0.0
5502120	20.80	59.80	19.40	0.0
5527050	13.00	50.50	36.50	0.0
5536265	30.71	45.26	24.02	0.01
5541750	15.00	53.95	31.05	0.0
5551800	15.00	65.00	20.00	0.00
5554600	14.75	61.40	23.85	0.0
5555400	15.00	62.40	22.60	0.0
5557100	15.00	65.00	20.00	0.00
5558050	15.00	65.00	20.00	0.00
5558675	17.25	63.00	19.75	0.0
5566000	15.00	58.50	26.50	0.00
5572100	15.00	59.80	25.20	0.00
5577520	15.00	57.20	27.80	0.0
5577700	15.00	59.80	25.20	0.00
5586500	15.00	63.70	21.30	0.0
5587650	17.25	63.00	19.75	0.0
5591500	15.00	55.25	29.75	0.0
5594200	15.00	65.00	20.00	0.00
5595550	20.49	55.49	24.02	0.0
5596100	15.00	65.00	20.00	0.00
5599640	15.00	65.00	20.00	0.00
MISS 2425980	57.75	27.00	15.25	0.00
2435300	23.27	40.82	35.90	0.01
2435400	53.32	27.07	19.60	0.01
2437550	43.18	30.68	26.14	0.0
2440020	17.25	43.80	38.95	0.0
2441220	13.00	49.20	37.80	0.0
2447340	15.00	65.00	20.00	0.00
2475220	40.01	26.46	23.02	10.51
2477050	30.00	25.00	45.00	0.0
2478500	57.33	25.83	16.84	0.0
2479165	59.81	24.66	15.52	0.01
2481505	49.32	28.32	22.36	0.0
2485780	15.00	65.00	20.00	0.00
2485900	19.50	61.00	19.50	0.0
2487670	60.00	25.00	15.00	0.0
2487710	60.00	25.00	15.00	0.0
2488550	60.00	25.00	15.00	0.0
2488680	37.99	42.24	19.76	0.01
2489030	60.00	25.00	15.00	0.0
2489140	57.33	25.83	16.84	0.0
7029252	33.41	33.36	33.24	0.0
7267200	25.98	45.98	28.04	0.0
7277550	26.89	44.39	28.71	0.01
7282300	16.83	61.83	21.34	0.0
7285700	17.20	61.20	21.61	0.0
7287140	18.16	54.81	27.02	0.01
7287520	29.64	39.64	30.72	0.0
7288568	30.00	25.00	45.00	0.0
7289640	15.00	65.00	20.00	0.00
7290220	25.98	45.98	28.04	0.0
7290525	15.00	65.00	20.00	0.00
7290910	17.93	59.93	22.14	0.0
7294400	15.00	65.00	20.00	0.00
7372550	15.00	65.00	20.00	0.00
7374235	39.96	40.96	19.09	0.0
7376665	33.00	49.00	18.00	0.0
7376760	26.72	54.52	18.76	0.0
MO 5497700	22.25	58.50	19.25	0.0
5502700	22.25	57.20	20.55	0.0
5503000	15.00	65.00	20.00	0.00
6815550	15.00	65.00	20.00	0.00
6816000	15.00	65.00	20.00	0.00
6820000	15.00	65.00	20.00	0.00
6857700	21.60	54.00	20.81	3.59
6902900	38.20	44.20	17.60	0.0
6902800	44.00	39.00	17.00	0.0
6907200	15.33	63.33	20.14	1.20
6908300	15.00	65.00	20.00	0.00
6909700	15.00	65.00	20.00	0.00
6910250	32.04	32.64	32.32	3.00
6918700	20.81	35.81	22.38	21.00
6919200	27.69	34.49	28.92	9.00
6921740	19.50	53.78	24.31	2.41
6925300	18.15	38.60	25.25	18.00
6927100	17.25	63.00	19.75	0.0
6931500	33.30	33.30	33.40	0.0
6935800	15.00	65.00	20.00	0.00
7011200	21.47	37.27	22.06	19.20
7011500	33.30	33.30	33.40	0.0
7015500	33.30	33.30	33.40	0.0
7017500	15.00	65.00	20.00	0.00
7064300	23.13	28.93	22.74	25.20
7064500	22.97	24.97	23.26	28.80
7185500	19.56	42.06	21.87	16.51
TENN 3313600	20.81	35.81	22.38	21.00
3313620	20.81	35.81	22.38	21.00
3418900	28.80	23.55	22.14	25.51
3420360	15.00	64.35	20.65	0.00
3420380	15.00	62.40	22.60	0.0
3420400	15.00	62.40	22.60	0.0
3430400	10.32	31.12	16.57	41.99
3431920	26.40	25.65	22.44	25.51

Table D.4 , continued

SAMPLE	% SAND	% SILT	% CLAY	% COARSE
3431580	35.72	32.72	19.56	12.00
3431600	30.75	28.95	21.10	19.20
3431650	35.72	32.72	19.56	12.00
3435020	18.73	46.23	21.53	13.51
3435030	18.32	48.32	21.36	12.00
3435600	16.33	58.33	20.54	4.80
3461200	23.30	23.30	23.40	30.00
3469110	22.97	24.97	23.26	28.80
3486725	26.42	42.26	21.73	9.59
3519610	15.00	53.95	31.05	0.0
3519630	15.58	51.38	30.04	3.00
3519640	15.26	52.26	30.07	2.41
3519650	14.16	52.06	32.27	1.51
3535140	39.95	31.05	19.99	9.01
3535160	21.92	39.92	24.97	13.19
3535180	24.86	35.71	21.42	18.01
3538500	33.76	24.96	20.87	20.41
3539100	42.68	24.93	18.88	13.51
3597300	20.64	35.08	23.87	20.41
3597400	20.64	36.64	22.31	20.41
3597450	20.81	35.16	23.03	21.00
3597500	20.98	34.46	22.97	21.59
3597550	21.72	33.57	23.70	21.01
3604070	22.47	27.47	23.06	27.00
3604080	22.97	24.97	23.26	28.80
3604090	22.30	28.30	22.99	26.41
3604100	22.30	28.30	22.99	26.41
7026535	20.80	59.80	19.40	0.0

Table D.5 Values Determined for Soils Characteristics for Sites in Study

SAMPLE	DBR	AVE AWC	AHORPERM	AVE PERM	HSGINFIL	MEASKSAT	MEAS KUN	MEAS PS	M RGF15B	M RGF3B
ALA 2342200	68.8000	2.3670	4.1870	3.2730	0.2250	1.7770	0.0151	13.3600	186.3300	32.5100
2343700	60.5000	3.1560	4.1880	2.9000	0.2160	2.5380	0.0105	10.8050	210.3500	38.4700
2362745	54.0000	2.1520	2.7130	2.4360	0.2250	2.4200	0.0114	9.9880	224.9360	40.7700
2363955	56.7000	2.3280	3.2370	3.1060	0.1860	2.8100	0.0086	11.9590	195.2200	36.6300
2365310	100.8000	1.2230	6.6850	6.6850	0.1987	2.3600	0.0118	9.6850	229.5000	41.4100
2371200	88.2000	3.6760	3.0790	2.3170	0.2055	2.7020	0.0093	11.6910	196.4300	36.4700
2372510	54.0000	2.4110	5.7730	4.3640	0.2152	2.5400	0.0105	10.5940	215.7900	39.5000
2359800	63.4000	3.8770	1.2680	1.2680	0.0878	1.6080	0.0069	13.6080	117.9800	17.4800
2400033	80.3000	5.0020	3.2040	3.1900	0.2012	1.3540	0.0176	13.8540	153.4500	24.3400
2400590	37.3000	2.0250	1.1420	1.3350	0.1170	1.1430	0.0116	10.2670	168.4100	22.3800
2407990	57.1000	2.7580	1.0960	1.0960	0.1077	0.8390	0.0031	9.1890	192.4700	24.5200
2408340	55.2000	4.0520	3.4680	2.0500	0.2400	1.4000	0.0170	10.3940	162.2700	25.4200
2410000	69.1000	4.6690	3.0740	2.1100	0.1840	1.2620	0.0222	16.3300	145.2900	24.8600
2412320	55.7000	3.2210	3.0690	2.5880	0.1330	1.6270	0.0121	11.0940	153.8200	24.2900
2413400	85.0000	4.6710	3.8100	2.3020	0.2100	1.7620	0.0181	14.6650	181.5900	32.6900
2414830	62.6000	4.4020	3.4120	1.7190	0.1460	1.4000	0.0170	10.3940	162.2700	25.4200
2417400	63.9000	4.3170	3.4750	2.3530	0.1925	1.5110	0.0195	14.2660	167.4300	28.9400
2421300	72.0000	4.5000	1.9720	1.9490	0.2250	2.3230	0.0128	9.7680	222.4600	39.8500
2427013	77.1000	3.5019	0.6130	0.6130	0.0685	0.4200	0.0400	5.2830	180.1300	22.9500
2437800	60.0000	2.8330	5.1230	5.1230	0.2480	1.6820	0.0208	8.4350	207.9700	34.2700
2437900	67.8000	3.0170	7.7740	7.7740	0.3490	2.3120	0.0121	9.7200	226.1400	40.6100
2449400	82.7000	3.2350	1.0400	1.0400	0.0772	0.7480	0.0313	7.2590	174.4100	22.5200
2450200	25.6000	1.6200	2.4000	2.3890	0.1424	1.3480	0.0061	9.5210	200.8100	29.1900
2451550	39.4000	2.9460	4.3320	3.6600	0.1650	2.3600	0.0118	9.6850	229.5000	41.4100
2451750	29.9000	2.3090	4.3350	3.9770	0.1487	2.1800	0.0113	9.8710	218.4500	37.9900
2453900	91.8000	3.2730	1.1250	1.1250	0.1000	1.6620	0.0076	9.4330	213.5500	33.7900
2462600	51.6000	2.1650	1.6890	1.6890	0.2125	1.5240	0.0063	9.7220	199.6900	30.3900
2465205	68.5000	1.7550	1.7810	1.4920	0.1492	2.2640	0.0123	9.7560	222.7800	39.6100
2471026	131.8000	2.4110	5.8850	3.2930	0.2520	1.7070	0.0148	10.4150	177.2000	29.2600
2479983	91.0000	2.6260	4.0210	3.3960	0.2200	2.5460	0.0102	11.4590	194.2700	35.5000
1574405	13.2000	0.7370	2.3480	1.8620	0.0556	1.6070	0.0152	10.1730	179.6800	29.2200
1585380	78.0000	2.8640	1.2390	1.2540	0.1208	0.8100	0.0024	9.1260	194.0600	24.4700
CA 2189020	125.8000	3.1550	4.0590	2.2980	0.2220	1.3900	0.0255	7.6010	203.1200	31.9100
2189030	98.4000	3.1760	4.1300	2.2970	0.2250	0.8080	0.0344	6.1640	190.0100	26.6500
2191270	49.7000	2.7360	3.6590	2.5830	0.2250	1.2020	0.0217	16.4860	184.0100	31.7200
2191230	121.5000	6.1800	3.9370	2.2750	0.2250	1.8080	0.0094	7.2400	304.0801	50.9800
2191600	29.5000	2.3790	4.0920	2.5670	0.2250	1.4580	0.0113	8.2910	299.1699	49.2700
2191750	25.2000	2.3740	4.5050	2.8740	0.2250	1.8350	0.0059	7.5370	293.3599	49.3500
2192300	36.0000	2.3510	4.5200	2.6010	0.2250	2.3600	0.0118	9.6850	229.5000	41.4100
2192400	36.6000	2.4230	4.1780	2.5490	0.2250	2.1560	0.0137	11.0720	217.1700	39.2100
2192420	34.0000	2.2540	4.5060	2.6620	0.2250	2.1550	0.0142	11.4180	214.0900	38.6600
2193500	25.2000	1.8520	3.9320	2.7120	0.1957	1.2320	0.0248	19.2180	144.7200	26.2900
2201110	34.0000	1.7240	3.9560	3.6220	0.2172	2.2450	0.0124	9.7700	221.4300	39.4900
2201150	36.7000	1.7250	4.3130	3.9700	0.2094	2.1920	0.0127	9.9480	214.2300	37.9800
2201830	90.6000	4.1700	9.0250	5.6180	0.1780	2.7390	0.0089	12.0460	189.3800	35.2600
2202910	55.2000	1.2910	7.1820	6.7470	0.1637	2.4800	0.0109	10.2910	220.3600	40.1300
2202950	49.0000	1.8300	4.7540	4.1840	0.1715	2.3600	0.0118	9.6850	229.5000	41.4100
2204200	86.4000	3.8860	5.6020	2.9000	0.2200	1.6370	0.0196	15.5590	168.4500	30.1800
2211459	160.8000	3.4640	4.2340	2.7250	0.2150	1.6350	0.0139	10.7230	257.5701	43.7400
2215280	92.7000	3.4180	4.1500	3.1010	0.1384	2.7250	0.0090	12.1950	184.8600	34.3900

Table D.5 . continued

SAMPLE	DBR	AVE AWC	AHORPERM	AVE PERM	MSGINFIL	MEASKSAT	MEAS KUN	MEAS PS	M RGF15B	M RGF3B
2216610	110.2000	3.6800	7.7500	4.6280	0.2370	2.6480	0.0094	12.2520	179.4900	33.1100
2217250	109.0000	2.3520	4.5200	2.6030	0.2250	0.3100	0.0354	27.0180	75.3600	13.9100
2217403	105.3000	1.9590	4.3820	2.8960	0.2250	1.5400	0.0212	16.6180	167.6400	30.4100
2217560	108.0000	2.2690	4.5200	2.6640	0.2250	0.5150	0.0330	25.2840	90.7700	16.6600
2218100	85.0000	2.7150	3.4700	2.3710	0.2072	1.9700	0.0106	8.1980	272.6201	46.5800
2223700	66.6000	1.8950	4.6940	4.2160	0.1665	2.5700	0.0103	10.7460	213.5000	39.1800
2224700	69.2000	4.1720	4.0560	2.1820	0.1242	2.4030	0.0114	10.3480	214.9800	38.8600
2225330	52.9000	1.4030	5.9470	5.6930	0.1860	2.4560	0.0111	10.1700	222.1900	40.3900
2215980	92.7000	2.3940	4.3500	3.8770	0.1506	2.7490	0.0088	12.3170	183.0400	34.1300
2316720	99.4000	4.2200	5.9500	4.8510	0.0972	2.9600	0.0075	12.7170	183.7900	35.0300
2216260	104.4000	3.8080	9.3500	6.6790	0.0620	2.9600	0.0075	12.7170	183.7900	35.0300
2317710	103.5000	3.5020	6.4250	5.2890	0.1345	2.9600	0.0075	12.7170	183.7900	35.0300
2317760	49.7000	1.2410	6.0320	5.4740	0.1880	2.3220	0.0120	9.7130	226.8100	40.7700
2217765	43.9000	1.3520	6.6790	6.1690	0.1900	2.3600	0.0118	9.6850	229.5000	41.4100
2317770	49.4000	1.3160	6.6580	6.0000	0.1900	2.3840	0.0116	9.8060	227.6700	41.1600
2217775	50.4000	1.3150	6.6650	6.0320	0.1900	2.4200	0.0114	9.9880	224.9300	40.7700
2317780	50.4000	1.3520	6.5990	5.7120	0.1900	2.3600	0.0118	9.6850	229.5000	41.4100
2317795	79.9000	1.8320	5.5170	4.7080	0.1760	2.7200	0.0092	11.5040	202.0700	37.5800
2217845	32.2000	1.1720	4.9970	3.9470	0.1712	2.1680	0.0128	9.8270	216.0500	38.2100
2317905	80.6000	1.8900	5.9200	5.0310	0.1590	2.6720	0.0096	11.2610	205.7300	38.0900
2317910	94.0000	2.7820	4.8640	4.0440	0.1108	2.7100	0.0090	12.3450	180.3500	33.4900
2318015	107.5000	3.9320	5.9770	4.5150	0.1397	2.5700	0.0099	12.1360	178.4100	32.6300
2318020	105.3000	5.5140	5.2000	2.3130	0.1087	2.1800	0.0122	11.5550	173.0300	30.2200
2327350	82.9000	2.3430	5.9470	4.9480	0.2142	2.3550	0.0117	10.1060	218.6400	39.3700
2327400	59.0000	1.2430	6.8170	6.7460	0.1900	2.3600	0.0118	9.6850	229.5000	41.4100
2346193	30.5000	1.9490	4.1590	2.7090	0.2250	2.0370	0.0150	11.8220	205.6200	36.8300
2346710	30.1000	1.9650	4.0720	2.6780	0.2250	1.0530	0.0264	20.1410	131.6400	23.6300
2346217	30.1000	2.1220	3.8590	2.6150	0.2250	0.7340	0.0305	21.1760	115.3600	19.9500
2350520	90.0000	1.9260	5.7150	4.8570	0.1672	2.5100	0.0107	10.4430	218.0700	39.8200
2381100	104.4000	2.4240	4.1500	2.9800	0.1150	2.2080	0.0112	9.3990	235.9100	41.5900
2381600	104.4000	2.8170	4.6300	2.9530	0.1500	2.1970	0.0103	9.6240	229.0900	40.1900
2381900	108.0000	2.1380	4.1500	2.9650	0.1150	2.2380	0.0120	9.5210	231.0500	41.0500
2382300	35.3000	1.1130	3.6660	3.6290	0.0506	0.8100	0.0024	9.1260	194.0600	24.4700
2382900	69.9000	4.3040	1.8870	1.3270	0.1350	1.5600	0.0112	15.1760	122.6000	19.5800
2387050	96.1000	3.3660	1.6870	1.6020	0.1242	1.4650	0.0065	13.7070	119.6300	16.9800
2387300	56.7000	2.9370	3.6450	3.9380	0.0937	0.8390	0.0031	9.1890	192.4700	24.5200
2387560	90.0000	3.0930	1.1960	1.2180	0.1177	1.2710	0.0130	16.9130	104.2300	15.7200
2397700	69.8000	4.4050	3.7140	2.6620	0.1194	1.7280	0.0111	10.1970	189.8000	30.7300
2307800	31.6000	1.4220	2.3850	2.3850	0.1600	1.5240	0.0032	11.9550	130.6600	17.9500
2388200	54.6000	2.3430	1.9320	2.2840	0.1575	1.3240	0.0064	13.1490	132.1400	18.2700
2386490	42.7000	2.1930	2.2170	2.2800	0.1650	1.2540	0.0110	15.6530	115.5200	16.7900
2397750	21.7000	0.4400	1.2080	1.2080	0.1048	1.1930	0.0194	15.7360	123.4800	19.5300
3566560	34.2000	1.7390	2.1270	2.1270	0.1810	1.3680	0.0058	9.3270	206.8200	30.5700
3566687	33.6000	1.3900	2.6910	2.6910	0.1722	0.8720	0.0028	9.1480	195.4700	25.1500
ILL 3338100	108.0000	9.3340	1.3000	1.3000	0.2250	0.8540	0.0090	9.7980	181.5300	20.9100
3344250	105.0000	6.1740	0.7240	0.6600	0.0615	0.8100	0.0024	9.1269	194.0600	24.4700
3390330	108.0000	6.9590	0.4340	0.2220	0.0370	0.8100	0.0024	9.1260	194.0600	24.4700
3380450	108.0000	6.1300	1.1020	1.0900	0.0930	1.0920	0.0027	10.2430	169.0300	21.9000
3381600	108.0000	6.4240	1.3000	1.3000	0.2250	0.9240	0.0053	9.3800	187.7000	24.6600
3382025	82.5000	5.9580	1.3000	1.3000	0.1187	0.8100	0.0024	9.1260	194.0600	24.4700

Table D.5 , continued

SAMPLE	OMR	AVE AWC	AWORPERM	AVE PERM	HSGINFIL	MEASKSAT	MEAS KUK	MEAS PS	M RGF15B	M RGF3B
5418800	108.0000	6.0190	1.8640	1.6170	0.1750	0.8100	0.0024	9.1260	194.0600	24.4700
5437600	108.0000	5.6000	1.7190	1.7180	0.2250	1.3740	0.0031	11.3590	144.0100	19.3200
5438650	108.0000	6.9700	1.3840	1.3840	0.2187	0.8320	0.0057	9.4620	187.8000	22.6900
5439550	108.0000	5.9000	1.6670	1.6670	0.2162	0.9980	0.0026	9.8700	177.3700	22.7600
5448050	108.0000	8.5160	2.1100	1.5990	0.2100	0.9510	0.0055	9.5860	183.5500	23.7400
5465750	108.0000	9.6480	1.3000	1.3000	0.1900	0.8320	0.0057	9.4620	187.8000	22.6900
5495200	117.0000	9.7100	1.3000	0.9120	0.1825	0.9150	0.0042	9.6660	182.5800	22.7200
5502120	118.8000	9.1640	1.1200	0.6660	0.1610	0.9980	0.0026	9.8700	177.3700	22.7600
5527050	108.0000	5.3320	0.5430	0.4890	0.0405	0.9090	0.0173	10.6390	165.8800	16.4500
5536265	102.7000	5.4080	1.6640	1.4350	0.1352	1.3520	0.0115	11.0430	164.3300	20.8000
5541750	105.3000	6.4060	1.3000	1.3000	0.1187	0.9030	0.0165	10.5550	167.4500	16.8900
5551800	108.0000	5.6690	1.7190	1.7180	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
5554600	108.0000	5.8650	0.5750	0.1440	0.0440	0.8370	0.0065	9.5460	186.2300	22.2400
5555400	108.0000	8.8540	1.1200	0.7040	0.1000	0.8320	0.0057	9.4620	187.8000	22.6900
5557100	108.0000	9.1340	2.9200	1.6790	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
5558050	108.0000	5.6250	1.1900	0.5930	0.0930	0.8100	0.0024	9.1260	194.0600	24.4700
5558375	108.0000	6.2720	1.4350	1.3670	0.2125	0.8870	0.0029	9.1540	195.8300	25.3200
5566000	108.0000	9.4720	1.3000	1.1560	0.2000	0.8650	0.0107	9.9670	178.4000	20.0100
5572100	108.0000	8.2960	1.3000	0.8890	0.1550	0.8540	0.0090	9.7980	181.5300	20.9100
5577520	108.0000	8.8140	1.3000	1.0260	0.1200	0.8760	0.0124	10.1350	175.2700	19.1200
5577700	110.7000	8.7860	1.3000	0.8950	0.1487	0.8540	0.0090	9.7980	181.5300	20.9100
5586500	108.0000	6.9690	1.3670	1.2850	0.1680	0.8210	0.0041	9.2940	190.9300	23.5800
5587850	108.0000	6.5920	1.0760	0.8700	0.1235	0.8870	0.0029	9.1540	195.6300	25.3200
5591500	108.0000	8.9170	1.3000	1.0700	0.1750	0.8920	0.0148	10.3870	170.5800	17.7900
5594200	108.0000	7.2820	1.0680	0.4710	0.0887	0.8100	0.0024	9.1260	194.0600	24.4700
5595550	108.0000	6.9520	1.3000	1.3000	0.2250	0.9870	0.0068	9.5060	184.5200	24.7600
5596100	108.0000	6.2460	0.7470	0.6870	0.0650	0.8100	0.0024	9.1260	194.0600	24.4700
5595640	108.0000	7.5240	1.3000	1.3000	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
MISS 2429980	89.1000	3.9730	2.2720	2.1450	0.1400	2.2820	0.0113	9.6570	227.7300	40.5600
2435300	69.7000	6.5210	0.9710	0.5350	0.0555	1.2250	0.0170	10.6940	166.7000	20.6200
2435400	59.5000	3.0780	2.8740	2.0240	0.1582	2.1200	0.0131	9.8620	212.6900	37.4100
2437550	98.2000	2.7230	1.6330	1.5870	0.1937	1.7530	0.0145	10.2680	183.2200	30.5400
2440020	83.1000	7.1090	0.1650	0.0950	0.0455	0.7890	0.0234	9.3420	168.6600	17.9500
2441220	90.0000	9.2830	0.2300	0.1260	0.0475	0.9200	0.0190	10.8070	162.7500	15.5600
2447340	105.8000	6.6990	1.3150	0.9740	0.1003	0.8100	0.0024	9.1260	194.0600	24.4700
2475270	135.0000	8.8370	1.6990	1.0760	0.1712	1.8120	0.0089	10.5410	185.8300	30.3100
2477090	54.0000	2.6970	0.8440	0.7410	0.0397	0.4200	0.0400	5.2830	180.1300	22.9500
2478500	83.8000	2.5540	1.8610	1.3810	0.1147	2.2640	0.0123	9.7560	222.7800	39.8100
2479165	120.6000	7.9250	1.9070	2.1640	0.2237	2.3420	0.0118	9.8720	223.8500	40.2500
2481505	125.3000	6.7550	3.9250	3.6510	0.2104	1.9760	0.0139	9.9680	202.6100	35.0100
2485780	84.6000	6.8810	1.4920	1.4920	0.1000	0.8100	0.0024	9.1260	194.0600	24.4700
2485900	89.1000	5.5090	1.5650	1.4760	0.0930	0.9650	0.0033	9.1820	197.6000	26.1700
2487670	73.8000	3.0070	1.8270	1.8270	0.2250	2.3600	0.0118	9.6850	229.5000	41.4100
2487710	72.0000	1.8410	2.2340	2.2010	0.2250	2.3600	0.0118	9.6850	229.5000	41.4100
2488550	72.0000	2.4150	1.8900	1.8900	0.2250	2.3600	0.0118	9.6850	229.5000	41.4100
2488600	134.4000	7.1880	2.9200	1.4910	0.1300	1.5960	0.0088	9.5680	205.2400	32.2400
2489030	103.5000	2.9310	1.9600	1.8730	0.1975	2.3600	0.0118	9.6850	229.5000	41.4100
2489160	108.0000	3.4100	2.0940	1.7870	0.1650	2.2640	0.0123	9.7560	222.7800	39.8100
7029252	85.5000	6.1040	2.9550	2.9550	0.1795	1.4030	0.0169	10.4180	161.7600	25.3200
7267200	108.0000	7.2580	1.0470	0.9300	0.0750	1.1640	0.0112	9.8870	174.9900	25.0400

Table D.5 . continued

SAMPLE	DBR	AVE AWC	AMORPERM	AVE PERM	HSGINFIL	MEASKSAT	MEAS KUN	MEAS PS	M RGF15B	M RGF30
7277550	84.6000	5.3760	2.0120	1.8170	0.1325	1.1930	0.0119	9.9500	173.4000	25.0900
7292300	108.0000	4.3450	1.7750	1.7600	0.1050	0.9690	0.0039	9.2530	190.8800	24.5700
7285700	105.1000	6.8290	1.3150	1.3150	0.1910	0.8810	0.0042	9.2780	190.2400	24.5900
7287140	90.0000	5.0160	1.2130	0.4620	0.0712	0.8030	0.0121	8.9490	184.1200	22.5100
7287520	90.0000	5.4570	1.3150	2.5110	0.2250	1.2820	0.0141	10.1400	168.6300	25.2300
7288568	69.3000	6.6850	0.0890	0.0450	0.0300	0.4200	0.0400	5.2830	180.1300	22.9500
7289440	86.4000	6.1020	1.6160	1.6100	0.1000	0.8100	0.0024	9.1260	194.0600	24.4700
7290220	105.2000	5.0720	2.7950	1.6520	0.1712	1.1640	0.0112	9.8870	174.9900	25.0400
7290525	85.5000	7.5510	1.5660	1.5320	0.1000	0.8100	0.0024	9.1260	194.0600	24.4700
7290910	108.0000	6.1340	1.3150	1.3150	0.2250	0.9040	0.0047	9.3290	188.9700	24.6200
7294400	54.0000	6.4290	1.2800	1.2470	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
7372550	54.0000	6.4290	1.2800	1.2470	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
7375235	111.2000	6.1550	1.5760	1.5450	0.1390	1.6620	0.0087	9.6950	203.9200	32.3700
7376665	118.8000	4.9720	1.3150	1.3150	0.1500	1.4300	0.0062	9.3500	208.2300	31.2500
7376760	110.2000	5.3470	2.3360	1.6270	0.0956	1.1970	0.0035	10.2130	173.5400	23.4200
MO 5497700	54.0000	2.9160	1.0160	1.0160	0.0865	1.0450	0.0027	10.0570	173.2000	22.3300
5502700	112.5000	4.0750	1.1830	0.8970	0.0580	1.0560	0.0043	10.2250	170.0700	21.4400
5503000	126.0000	3.5850	1.0120	0.6220	0.0364	0.8100	0.0024	9.1260	194.0600	24.4700
6815550	108.0000	7.2600	1.3000	1.3000	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
6816300	54.9000	3.2500	1.3700	1.3700	0.2250	0.8100	0.0024	9.1260	194.0600	24.4700
6870000	57.6000	2.9820	1.4250	1.4250	0.2055	0.8100	0.0024	9.1260	194.0600	24.4700
6897700	53.9000	3.3120	1.0730	1.1140	0.1100	1.0160	0.0053	10.1390	172.3600	21.3300
6902500	46.9000	2.7500	1.5090	1.5090	0.1750	1.5620	0.0033	12.1040	127.2200	17.6100
6907800	45.0000	2.1000	1.7650	1.7650	0.2250	1.7500	0.0035	12.8480	110.6400	15.8900
6907200	54.0000	2.3770	2.2990	2.2990	0.0468	0.8480	0.0024	9.2750	190.7200	24.1300
6908300	144.0000	6.7930	1.3000	1.3000	0.2000	0.8100	0.0024	9.1260	194.0600	24.4700
6909700	51.9000	3.5260	3.9060	4.0940	0.1325	0.8100	0.0024	9.1260	194.0600	24.4700
6910250	49.9000	3.3030	0.9180	0.9180	0.0547	1.1520	0.0199	13.6550	146.4300	23.0700
6918700	54.6000	3.1960	1.0390	1.0390	0.0860	1.4680	0.0032	11.7320	135.6700	18.4600
6919200	54.0000	1.8600	1.6440	1.6440	0.2250	0.5100	0.0222	19.8610	122.8400	18.1400
6921740	69.4000	8.4930	1.0770	0.9870	0.1154	1.0580	0.0060	10.3560	167.7800	20.6300
6925300	59.0000	2.2650	2.0560	2.4010	0.1200	1.3010	0.0094	11.4530	143.9700	17.5400
6927100	49.0000	3.2310	1.2320	1.1910	0.0642	0.8870	0.0029	9.1540	195.8300	25.3200
6931500	63.0000	5.8750	0.8020	0.8020	0.0475	1.4000	0.0170	10.3940	162.2700	25.4200
6935900	54.0000	3.1870	0.9000	0.8430	0.0885	0.8100	0.0024	9.1260	194.0600	24.4700
7011200	180.0000	3.5670	2.9940	3.1940	0.1500	1.4350	0.0037	11.5590	139.4000	19.0200
7011500	54.0000	5.0690	4.0140	4.0140	0.1750	1.4000	0.0170	10.3940	162.2700	25.4200
7015500	48.6000	4.5650	1.1250	1.1250	0.1000	1.4000	0.0170	10.3940	162.2700	25.4200
7017500	88.2000	3.0800	1.1870	1.1820	0.1062	0.8100	0.0024	9.1260	194.0600	24.4700
7054300	180.0000	3.1280	3.4140	3.6210	0.1760	1.5530	0.0066	11.8130	133.0400	19.2100
7064500	51.1000	2.4500	2.5530	3.1340	0.1582	1.7120	0.0035	12.7000	113.9800	16.2300
7155500	67.0000	2.9690	1.8810	1.6600	0.1867	0.8570	0.0025	9.2120	189.8000	24.0400
TENN 3313600	54.0000	1.3060	3.6450	3.6450	0.2250	1.4680	0.0032	11.7320	135.6700	18.4600
3313620	54.0000	1.3440	3.5400	3.5400	0.2250	1.4680	0.0032	11.7320	135.6700	18.4600
3418900	43.9000	1.1350	5.6250	2.2360	0.1137	2.2640	0.0123	9.7560	222.7800	39.8100
3420360	130.5000	5.1920	1.2560	1.2560	0.1430	0.8150	0.0032	9.2100	192.4900	24.0300
3420380	129.6000	5.0680	1.3990	1.3990	0.1155	0.8320	0.0057	9.4620	187.8000	22.6900
3420400	131.0000	5.1210	1.2760	1.2760	0.1456	0.8320	0.0057	9.4620	187.8000	22.6900
3430400	30.6000	3.2510	0.5910	0.5230	0.0598	1.1200	0.0134	10.1380	171.2900	22.7900
3431520	69.3000	1.5790	3.7500	3.7500	0.2250	1.7500	0.0035	12.8480	110.6400	15.8900

Table D.5 , continued

SAMPLE	DBR	AVE AWC	AHORPERM	AVE PERM	HSGINFIL	MEASKSAT	MEAS KUN	MEAS PS	M RGF15B	M RGF3B
3431580	45.4000	1.5640	1.9650	1.9650	0.1400	1.7500	0.0035	12.8480	110.6400	15.8900
3431600	56.2000	1.4630	3.3300	3.3300	0.2050	1.7500	0.0035	12.8480	110.6400	15.8900
3431650	40.5000	1.5510	1.6500	1.6500	0.1250	1.7500	0.0035	12.8480	110.6400	15.8900
3435020	54.0000	1.2900	3.5400	3.5400	0.2250	1.2330	0.0029	10.8010	156.5200	20.6100
3435030	54.0000	1.3400	3.4140	3.4140	0.2250	1.1860	0.0028	10.6150	160.6900	21.0400
3435600	162.7000	5.3230	1.6550	1.5290	0.1800	0.8140	0.0031	9.1930	192.8000	24.1200
3461200	29.1000	1.3320	1.8130	1.7460	0.1036	1.6360	0.0136	10.0150	187.6000	30.4200
3469110	31.5000	1.6850	1.0510	0.9410	0.0856	1.1050	0.0051	9.3170	197.1800	27.2600
3496225	63.8000	2.4920	1.8800	1.8800	0.2044	1.3360	0.0053	11.1370	151.6800	19.9600
3519610	84.3000	3.1510	0.6050	0.5660	0.2187	0.9030	0.0165	10.5550	167.4500	16.8900
3519630	77.4000	3.1100	0.5000	0.5000	0.1975	0.8980	0.0157	10.4710	169.0100	17.3400
3519640	76.6000	3.2210	0.5000	0.5390	0.1830	0.8940	0.0150	10.4040	170.2700	17.7000
3519650	77.4000	2.8110	0.5000	0.5000	0.1850	0.8920	0.0148	10.3870	170.5800	17.7900
3535140	70.8000	2.9830	3.1960	2.3390	0.1212	1.5750	0.0075	10.2140	186.6200	28.2900
3535160	77.3000	2.7620	2.4300	2.1900	0.1340	1.1890	0.0088	9.6750	192.3400	26.1500
3535190	144.4000	3.0010	2.4730	2.8470	0.1782	1.0920	0.0056	10.1450	171.0400	22.4500
3538900	42.5000	1.1640	4.2140	2.2080	0.1650	2.1850	0.0055	10.5710	196.2200	34.2600
3539100	46.8000	1.3350	3.8130	2.5600	0.1700	2.2380	0.0101	10.3180	205.7300	36.3100
3597300	54.1000	2.5000	1.0920	1.0920	0.1008	1.0830	0.0109	9.8860	176.3100	23.8200
3597400	51.8000	2.6810	0.9980	0.9980	0.1014	1.0930	0.0094	9.7340	178.6000	24.9300
3597450	64.8000	2.4400	1.2940	1.2940	0.1380	1.0220	0.0083	9.6540	181.3700	24.3600
3597500	47.0000	2.7230	0.9830	0.9830	0.0908	1.1450	0.0112	9.9030	175.0000	24.6500
3597550	37.2000	2.3280	1.1340	1.0470	0.0632	1.2100	0.0144	10.2020	168.7000	23.7500
3604070	85.5000	4.7380	3.6320	3.6320	0.2090	1.6090	0.0033	12.2900	123.1500	17.1800
3604080	87.1000	4.7880	3.8460	3.8460	0.2250	1.7120	0.0035	12.7000	113.9800	16.2300
3604090	82.6000	4.5670	3.3250	3.3250	0.2200	1.6000	0.0033	12.2530	123.9900	17.2600
3604100	82.3000	4.5990	3.3330	3.3330	0.2150	1.6000	0.0033	12.2530	123.9900	17.2600
7028935	54.0000	1.7420	1.4420	1.4420	0.1900	0.9580	0.0026	9.8700	177.3700	22.7600

Table D.6 Values Determined for Climatic Characteristics for Sites in Study

SAMPLE	PRECIP	I24,2	I24,50
ALA 2347200	52.00	4.20	8.00
2343700	52.00	4.70	9.10
2362745	56.00	4.60	8.90
2363055	56.00	4.70	9.20
2365310	56.00	4.80	9.60
2371200	54.00	4.70	8.80
2372510	56.00	5.20	10.00
2358800	52.00	3.80	7.30
2400033	52.00	3.80	7.70
2400690	54.00	3.80	7.60
2407000	54.00	4.30	7.90
2409340	54.00	4.20	7.80
2410000	52.00	4.40	8.10
2412320	54.00	4.00	7.60
2413400	52.00	4.00	7.60
2414800	54.00	4.10	7.80
2417400	52.00	4.30	8.10
2421300	52.00	4.50	8.50
2427013	50.00	4.70	8.70
2437800	52.00	3.80	7.30
2437900	52.00	3.90	7.40
2445400	49.00	4.40	8.50
2450200	54.00	3.90	7.40
2451550	54.00	3.80	7.20
2451750	54.00	3.80	7.30
2453900	54.00	4.00	7.50
2462600	54.00	4.20	7.70
2465205	54.00	4.30	8.00
2471026	64.00	5.50	11.10
2475583	62.00	5.60	11.70
3574405	54.00	3.70	6.90
3585380	52.00	3.70	6.90
GA 2185070	54.00	4.00	7.60
2189020	54.00	3.95	7.60
2191270	50.00	3.85	7.40
2191280	52.00	3.90	7.50
2191600	50.50	3.80	7.30
2191750	48.00	3.70	7.30
2192300	46.00	3.50	7.30
2192400	46.00	3.50	7.40
2192420	44.00	3.50	7.30
2193600	46.00	3.50	7.50
2201110	42.30	3.60	7.50
2201160	42.20	3.59	7.50
2201830	43.10	3.77	7.70
2202910	44.60	3.88	7.80
2202950	45.80	3.97	7.80
2208200	48.50	3.78	7.70
2211459	48.00	3.80	7.60
2215200	43.80	3.84	7.80
2216610	46.20	4.00	7.80
2217250	51.00	3.85	7.50
2217400	51.00	3.85	7.40
2217660	52.00	3.90	7.60
2218100	48.50	3.70	7.50
2223700	44.50	3.74	7.50
2224200	45.00	3.79	7.60
2225330	45.20	3.91	7.60
2315980	45.00	3.90	7.80
2316220	45.70	3.97	7.90
2316260	47.40	3.89	7.90
2317710	47.70	3.97	7.90
2317760	44.00	3.92	7.80
2317765	44.00	3.91	7.80
2317770	43.90	3.91	7.80
2317775	44.90	3.94	7.90
2317780	44.50	3.94	7.90
2317795	45.90	3.97	7.90
2317845	47.00	4.03	8.00
2317905	46.70	4.02	8.00
2317910	47.20	4.09	8.00
2318015	48.10	4.20	8.10
2318020	49.00	4.25	8.20
2327350	50.20	4.37	8.40
2327400	50.00	4.22	8.40
2346193	49.10	3.92	7.80
2346210	49.00	3.91	7.90
2346217	49.10	3.90	7.70
2350520	45.50	3.96	7.90
2381100	53.50	4.00	7.50
2381600	54.00	3.92	7.90
2381900	53.50	3.94	7.50
2382800	53.50	3.94	7.40
2382900	52.50	3.89	7.40
2383000	52.50	3.65	7.40
2387300	53.00	4.00	7.20
2387560	52.00	3.92	7.30
2387700	52.50	3.92	7.20
2387800	53.00	3.94	7.00
2388200	52.50	3.93	7.10
2388400	52.50	3.94	7.20
2397750	52.50	3.90	6.90
3566660	53.00	3.89	6.90
3566687	53.00	3.94	6.90
ILL 3339100	38.70	3.00	5.50
3344250	39.60	3.20	5.80
3380300	43.40	3.40	6.10
3380450	40.70	3.40	6.10
3381600	41.37	3.30	6.10
3382025	42.50	3.50	6.30

Table D.6 , continued

SAMPLE	PRECIP	I24.2	I24.50
5418800	32.80	3.00	5.50
5437600	36.72	2.80	5.30
5438950	34.00	2.90	5.40
5435550	36.72	2.80	5.30
5448050	34.00	3.20	5.80
5465750	35.10	3.20	5.90
5495200	35.60	3.30	6.10
5502120	36.40	3.40	6.20
5527050	33.20	2.80	5.30
5536265	32.90	2.80	5.60
5541750	34.65	2.90	5.50
5551800	34.05	2.90	5.40
5554600	34.02	3.00	5.50
5555400	33.00	3.00	5.60
5557100	34.10	3.00	5.70
5558050	33.50	3.00	5.60
5558075	33.50	3.00	5.60
5564000	34.30	3.00	5.70
5572100	37.40	3.10	5.80
5577520	35.02	3.30	5.90
5577700	36.20	3.30	5.90
5586500	37.00	3.40	6.20
5587850	38.50	3.40	6.20
5591500	38.70	3.20	5.90
5594200	39.00	3.50	6.20
5595550	39.70	3.60	6.40
5596100	40.70	3.50	6.20
5599640	45.80	3.60	6.40
MISS 2429580	52.00	3.90	7.10
2435300	54.00	4.00	7.30
2435400	54.00	4.00	7.40
2433550	52.00	4.10	7.40
2440020	50.00	4.10	7.50
2441220	49.00	4.20	7.80
2447340	51.00	4.40	8.00
2475220	56.00	4.50	8.60
2477090	58.00	4.50	8.80
2478600	59.00	4.80	9.70
2479165	64.00	5.10	11.00
2481505	64.00	5.40	11.30
2485730	52.00	4.50	8.60
2485900	52.00	4.50	8.70
2487670	53.00	4.50	8.80
2487710	54.00	4.50	8.80
2488550	54.00	4.60	9.00
2488880	56.00	4.70	9.20
2489030	58.00	4.80	9.70
2489160	58.00	4.80	9.80
7025252	56.00	3.90	7.10
7267200	55.00	4.10	7.40
7277550	52.00	4.10	7.40
7282300	52.00	4.20	7.60
7285700	52.00	4.20	7.60
7287140	52.00	4.30	7.80
7287520	52.00	4.40	8.20
7288568	52.00	4.30	7.80
7289640	52.00	4.40	8.30
7290220	57.00	4.70	9.20
7290525	54.00	4.50	8.80
7290910	56.00	4.80	9.30
7294400	58.00	4.90	9.50
7373550	60.00	4.80	9.70
7375235	60.00	4.90	9.70
7376665	61.00	4.90	9.70
7376760	60.00	4.90	9.70
NO 5497700	36.00	3.30	6.30
5507700	36.00	3.40	6.40
5503000	36.00	3.40	5.40
6815550	34.00	3.30	6.60
6816000	34.00	3.40	6.70
6820000	34.00	3.30	6.60
6857700	35.00	3.40	6.60
6502500	36.00	3.40	6.50
6902800	36.00	3.40	6.50
6907200	38.00	3.50	6.80
6908300	38.00	3.50	6.70
6909700	38.00	3.50	6.70
6910250	38.00	3.50	6.70
6518700	42.00	3.80	7.30
6519200	40.00	3.80	7.20
6521740	38.00	3.50	7.00
6925300	42.00	3.70	7.00
6927100	38.00	3.50	6.60
6531500	42.00	3.70	6.80
6935800	36.00	3.50	6.50
7011200	42.00	3.70	6.80
7011500	42.00	3.70	6.80
7015500	42.00	3.60	6.80
7017500	42.00	3.60	6.60
7064300	42.00	3.70	6.90
7064500	42.00	3.70	6.90
7185500	42.00	3.90	7.50
TENN 3313600	51.00	3.40	6.20
3313620	51.00	3.40	6.20
3418900	51.00	3.60	6.50
3420360	51.00	3.60	6.60
3420380	51.00	3.60	6.60
3420400	51.00	3.60	6.60
3430400	47.00	3.50	6.50
3431520	47.00	3.40	6.40

Table D.6 , continued

SAMPLE	PRECIP	I24.2	I24.50
3431580	47.00	3.50	6.40
3431600	47.00	3.40	6.40
3431650	48.00	3.50	6.40
3435020	48.00	3.30	6.20
3435030	49.00	3.30	6.20
3435500	48.00	3.30	6.30
3461200	57.00	3.50	6.40
3469110	52.00	3.40	6.40
3486225	46.00	2.60	6.00
3519610	51.00	3.50	6.60
3519630	51.00	3.50	6.60
3519640	51.00	3.50	6.60
3519650	51.00	3.50	6.60
3535140	49.00	3.40	6.20
3535160	49.00	3.40	6.20
3535180	49.00	3.40	6.20
3538900	52.00	3.60	6.50
3539100	51.00	3.60	6.40
3597300	52.00	3.50	6.60
3597400	52.00	3.50	6.60
3597450	52.00	3.50	6.60
3597500	52.00	3.50	6.60
3597550	52.00	3.50	6.60
3604070	52.00	3.80	6.70
3604080	52.00	3.80	6.70
3604090	52.00	3.80	6.70
3604100	52.00	3.80	6.70
7028935	52.00	3.50	6.80

Table D.7 Final Calibrated Parameter Values for PSP, KSAT, RGF, BMSM, KSW and TC for sites in Study

	SAMPLE	PSP	KSAT	RGF	BMSM	KSW	TC
ALA	2342200	2.2800	0.1030	13.3000	4.0600	4.7500	150.0000
	2343700	5.4200	0.1450	4.1100	9.0900	3.1000	270.0000
	2362745	3.1700	0.1300	12.4000	8.0900	4.0500	202.0000
	2363055	5.8800	0.1140	2.1200	4.0500	2.6300	215.0000
	2365310	2.3600	0.0400	34.6000	1.4600	1.9200	136.0000
	2371200	5.7200	0.1540	5.5600	6.6000	6.5000	420.0000
	2372510	1.8900	0.0640	25.0000	3.8000	4.4600	332.0000
	2359900	1.9500	0.0700	15.5000	3.9000	8.1300	390.0000
	2400023	2.9800	0.0850	18.9000	8.1700	6.6000	100.0000
	2400690	4.4800	0.0360	34.0000	7.8800	5.8900	284.0000
	2407900	5.2600	0.0860	8.6300	6.5000	4.5000	254.0000
	2408340	2.4600	0.0750	18.8000	6.6000	5.2500	330.0000
	2410000	7.8500	0.0810	16.2000	6.6000	1.5000	105.0000
	2412220	2.8900	0.0360	13.3000	10.9000	2.6500	111.0000
	2413400	3.3500	0.0910	10.3000	2.5100	1.8000	240.0000
	2414800	5.0400	0.0580	4.3800	2.8300	2.5000	165.0000
	2417400	1.0700	0.1170	10.8000	2.7400	1.0000	75.0000
	2421300	9.1100	0.0920	8.2400	5.4400	4.5000	300.0000
	2427013	4.6000	0.0100	39.4000	14.7000	1.4200	71.0000
	2437800	1.2600	0.0680	21.0000	5.6500	8.0000	300.0000
	2437900	2.7500	0.1020	9.3800	4.8000	7.0000	210.0000
	2449400	1.2700	0.0320	11.9000	2.2100	1.8500	300.0000
	2450200	1.8900	0.0470	10.7000	6.3200	8.5000	210.0000
	2451550	8.6100	0.1040	33.4000	6.6000	1.0000	45.0000
	2451750	2.9200	0.0870	14.6000	6.4800	1.2500	75.0000
	2453900	2.9600	0.0600	8.2400	4.8500	7.8000	168.0000
	2462600	2.4000	0.0690	40.1000	6.6000	6.0000	120.0000
	2465205	4.9700	0.1080	13.9000	5.2400	2.5000	90.0000
	2471026	5.6700	0.1620	11.9000	1.7200	1.0500	142.0000
	2479583	9.9700	0.1110	14.4000	6.1000	6.6000	240.0000
	3574405	2.1400	0.0460	5.7900	3.2800	0.4800	437.0000
	3585380	2.5000	0.0720	39.9000	10.7000	4.6900	848.0000
GA	2189020	1.5400	0.1400	6.4000	5.5100	2.1000	350.0000
	2189030	1.2400	0.0570	11.4000	3.0100	1.8500	35.0000
	2191270	2.3000	0.1200	8.0100	9.9100	3.9500	465.0000
	2191280	0.6700	0.1050	25.8000	4.5900	0.5700	43.9000
	2191600	1.6000	0.1500	12.2000	4.0100	1.6500	250.0000
	2191750	0.9000	0.0870	11.9000	4.4800	6.3000	490.0000
	2192300	1.3700	0.0480	12.1000	3.0500	0.7000	55.0000
	2192400	1.6200	0.1000	16.3000	3.7500	3.2600	255.0000
	2192420	3.8000	0.1300	14.6000	4.7800	1.6800	55.0000
	2193600	0.7600	0.1200	12.7000	8.7000	0.8800	77.0000
	2201110	2.1500	0.0570	20.5000	2.7600	12.9000	410.0000
	2201160	1.5500	0.0680	25.1000	7.7100	6.1500	285.0000
	2201530	0.8800	0.2500	13.3000	9.5700	7.7100	500.0000
	2202910	1.5200	0.1370	18.7000	4.6000	4.1800	189.0000
	2202950	1.4900	0.0750	7.6600	8.0000	6.4000	365.0000
	2208200	2.3200	0.1200	21.5000	4.2700	1.4900	110.0000
	2211459	2.8700	0.1300	12.1000	5.2000	1.8800	101.0000
	2215280	0.8300	0.1500	24.8000	10.1000	4.7600	257.0000

Table D.7 , continued

SAMPLE	PSP	KSAT	RGF	BMSM	KSM	TC
2216610	1.2100	0.1030	10.8000	6.4600	4.4400	351.0000
2217250	2.4100	0.1400	11.7000	10.0000	1.1000	40.0000
2217400	2.2300	0.1090	3.2800	8.5300	1.8900	120.0000
2217660	1.8100	0.2000	22.9000	9.7700	0.6800	45.0000
2218100	0.9700	0.0820	21.7000	2.6500	2.6900	90.0000
2222700	2.2900	0.1200	6.8700	3.2800	5.9600	204.0000
2224200	3.3400	0.1100	5.2200	4.7700	13.2000	808.0000
2225330	1.3500	0.0570	13.6000	8.4400	16.0000	644.0000
2315560	0.9400	0.1000	15.6000	6.3000	4.7500	220.0000
2316220	1.9800	0.1200	28.3000	5.9500	8.8900	250.0000
2316260	0.7400	0.0240	13.2000	9.0100	21.5000	475.0000
2317710	1.5100	0.1160	12.2000	7.9500	5.3000	198.0000
2317760	0.8200	0.0640	11.9000	3.6200	18.1000	900.0000
2317765	1.3900	0.1100	42.9000	6.5000	5.4500	360.0000
2317770	0.7000	0.1200	9.6000	4.8000	18.1000	600.0000
2317775	0.9900	0.0930	22.1000	4.6300	4.4000	170.0000
2317780	0.9100	0.0800	18.9000	6.1900	2.9800	116.0000
2317795	0.7300	0.0820	38.4000	5.9500	9.5000	570.0000
2317845	1.7200	0.0390	22.3000	8.4300	5.6000	192.0000
2317905	1.0300	0.1100	24.2000	6.1200	6.8000	300.0000
2317910	0.8300	0.0700	30.5000	6.6900	6.0000	266.0000
2318015	0.5200	0.0920	12.0000	3.0900	6.2400	250.0000
2318020	0.6200	0.0320	12.9000	8.8000	2.0000	85.0000
2327350	0.7100	0.0290	26.5000	4.0400	5.2200	241.0000
2327400	0.7900	0.0990	32.5000	5.4100	7.1600	350.0000
2346153	1.7400	0.1000	13.3000	6.1400	2.2600	130.0000
2346710	1.9400	0.0430	20.8000	8.4500	4.2100	165.0000
2346217	3.3000	0.1910	9.7700	3.3200	2.2700	118.0000
2350520	0.8900	0.0610	12.2000	2.7700	6.7000	440.0000
2381100	3.7300	0.2400	5.3400	8.6900	2.8000	85.0000
2381600	6.7600	0.0610	13.8000	9.6600	5.4000	180.0000
2381900	3.8000	0.0760	3.6200	8.7400	3.0000	110.0000
2382800	2.1100	0.0420	22.2000	3.0000	4.3900	110.0000
2382900	0.8200	0.0740	21.1000	4.2600	8.5000	450.0000
2383000	1.2300	0.0640	16.5000	4.1100	5.9700	250.0000
2387300	1.0000	0.0330	25.0000	7.4100	0.9300	45.0000
2387560	2.7000	0.1030	17.8000	7.1600	2.3800	120.0000
2387700	2.1200	0.0270	21.8000	2.0300	6.5800	380.0000
2387800	1.3300	0.0540	10.3000	2.9600	5.3200	137.0000
2388200	1.4500	0.0730	5.0000	9.0600	4.8200	224.0000
2388400	3.1900	0.0760	21.6000	6.3300	2.7500	115.0000
2357750	0.8800	0.0240	24.6000	2.1800	8.0600	325.0000
3566660	1.0000	0.0470	18.8000	4.0200	4.5600	230.0000
3566687	2.1900	0.0710	20.7000	2.0500	3.6900	175.0000
ILL 2338100	1.7100	0.0540	24.9000	1.9200	2.5400	174.0000
3344250	0.7800	0.0270	24.6000	1.3100	1.6600	24.0000
3380300	3.3300	0.0400	16.3000	1.5000	0.0900	45.0000
3380450	1.6200	0.0400	28.0000	2.0000	0.3400	90.0000
3381600	3.4900	0.0760	16.2000	1.1700	0.2100	46.0000
3382025	0.8600	0.0660	2.0900	7.1500	0.5000	94.0000

Table D.7 , continued

SAMPLE	PSP	KSAT	RGF	BKSN	KSW	TC
5418800	2.5500	0.0660	22.1000	1.6600	0.4200	87.0000
5437600	3.6100	0.1900	14.0000	4.0000	1.0000	169.0000
5438850	4.6800	0.0810	27.3000	5.4000	1.4500	55.0000
5439550	2.8100	0.0950	12.7000	1.4600	0.8000	110.0000
5448050	3.3100	0.1720	15.5000	8.1600	0.4200	67.0000
5469750	2.6500	0.1310	16.9000	6.0000	0.6300	74.0000
5495200	1.4100	0.0700	21.9000	3.0700	0.7200	68.0000
5502120	1.9200	0.0510	11.9000	1.1800	0.5700	59.0000
5527050	1.0800	0.0500	5.7900	1.6900	1.5000	250.0000
5536265	0.4500	0.0500	14.5000	3.9930	19.9000	747.0000
5541750	0.4500	0.0820	9.3800	2.7400	19.0000	330.0000
5551800	0.6100	0.0580	20.6000	1.1600	0.6900	113.0000
5554600	0.3000	0.0500	4.8400	4.9900	0.8200	49.0000
5555400	2.3100	0.0930	17.3000	1.7700	0.3400	15.3000
5557100	2.1300	0.1440	13.1000	4.9800	0.3600	33.0000
5558050	3.0600	0.0650	9.4200	3.4200	0.1000	24.6000
5556075	3.8800	0.0810	11.8000	5.9900	0.1100	63.0000
5566000	1.2800	0.0500	39.2000	4.9900	7.5000	205.0000
5572100	0.9500	0.0820	20.1000	4.0000	0.4300	35.0000
5577520	3.9600	0.2160	13.4000	3.1400	0.4800	36.0000
5577700	2.7000	0.0960	27.7000	2.2600	1.4400	66.0000
5586500	2.7800	0.2120	22.4000	4.9200	1.4500	94.0000
5587850	3.4900	0.0550	18.3000	3.0000	0.7100	33.0000
5591500	0.7400	0.0510	19.2000	2.3500	17.3000	360.0000
5594200	1.1800	0.0510	3.9800	1.9300	1.6200	182.0000
5595550	4.1700	0.0700	10.1000	1.5300	0.5100	30.0000
5596100	1.4900	0.0510	27.4000	2.0000	0.5000	203.0000
5599640	4.4900	0.1350	23.0000	1.3200	0.3200	16.2000
MISS 2425980	4.2000	0.0700	10.7000	5.1600	2.8600	224.0000
2435300	0.4100	0.0120	2.0100	1.8200	0.5400	44.6000
2435400	2.7000	0.0490	15.6000	3.0700	2.4400	224.0000
2437550	4.5200	0.0300	9.8400	4.0000	1.2000	130.0000
2440020	3.0300	0.0180	20.2000	5.4000	0.5000	40.0000
2441720	1.0100	0.0340	10.2000	2.7000	1.5000	75.0000
2447340	1.1600	0.0240	15.0000	2.2500	4.3900	469.0000
2475720	4.7200	0.1420	8.2000	9.9300	1.4100	62.8000
2477050	0.8600	0.0190	7.5600	5.6700	1.3500	60.3000
2477090	0.8800	0.0160	8.9100	7.4200	0.8600	143.0000
2478600	0.8500	0.0230	10.1000	1.8600	1.1600	124.0000
2475165	2.8400	0.0360	7.9000	1.1400	1.9500	243.0000
2481505	3.1300	0.0540	12.9000	3.1500	3.6000	243.0000
2485780	4.3900	0.0330	5.2400	4.5400	0.4800	66.6000
2485900	3.4100	0.0440	8.1700	13.8000	2.3400	278.0000
2485700	2.0500	0.0520	8.7200	1.9400	2.1000	165.0000
2487670	4.9700	0.1040	19.8000	9.3600	1.0500	99.0000
2487710	2.9500	0.0450	9.0600	3.2600	2.3000	250.0000
2488550	5.7500	0.0730	30.0000	6.3000	0.5800	113.0000
2488680	3.4200	0.0740	6.8900	5.9600	0.8800	109.0000
2489020	3.2400	0.0330	16.7000	1.8200	1.8000	39.0000
2489160	4.9600	0.1080	17.2000	6.5200	0.7400	129.0000

Table D.7 , continued

SAMPLE	PSP	KSA	RGF	BMSM	KSW	TC
7029252	2.9400	0.0470	8.7800	6.4800	0.7700	43.2000
7267200	1.4000	0.0180	5.9100	4.8600	1.8900	83.3000
7277650	1.1300	0.0120	2.4300	1.2200	0.8200	40.0000
7282300	1.9600	0.0440	11.4000	3.7700	1.8000	36.0000
7285700	2.3200	0.0780	3.4500	6.9600	0.6800	108.0000
7287140	1.0500	0.0130	2.6300	6.4400	2.7000	108.0000
7287520	1.8300	0.0290	14.3000	3.7400	0.5100	91.0000
7287520	1.3700	0.0230	16.7000	2.0200	1.0500	72.0000
7288568	1.0500	0.0180	3.2900	3.3400	7.2000	234.0000
7289640	1.1500	0.0160	9.4100	6.4800	0.4400	149.0000
7289640	2.1900	0.0130	7.7700	5.5700	0.6000	22.0000
7290220	3.0700	0.0400	8.6400	4.1400	0.8700	119.0000
7290525	1.4000	0.0280	15.2000	3.7600	1.3300	171.0000
7290910	3.5700	0.0570	8.6600	3.0500	1.2200	25.7000
7294400	3.2800	0.0460	11.3000	3.6500	0.8800	17.1000
7294400	1.9400	0.0220	7.1800	8.0700	1.0100	21.6000
7373550	1.3600	0.0230	7.6600	3.5900	0.7900	44.6000
7375235	4.8400	0.0480	9.9000	5.6700	4.6600	300.0000
7376665	2.1000	0.0480	10.4000	8.4800	1.1100	168.0000
7376665	4.9200	0.0240	14.1000	7.3500	1.2000	69.3000
7276760	1.3700	0.0200	3.9500	6.8100	2.2300	230.0000
MO5497700	1.4500	0.0280	17.8000	4.0000	1.5000	226.0000
5507700	2.4100	0.0270	13.5000	4.8000	0.8000	60.0000
5507000	1.4100	0.0330	19.7000	2.0000	1.7500	75.0000
6815550	1.1400	0.0200	6.8200	6.1500	0.7500	40.0000
6816000	3.5400	0.0820	10.3000	5.7500	0.6500	66.0000
6820000	1.9000	0.0440	9.2900	3.6900	2.0000	135.0000
6897700	2.5000	0.0270	9.4500	6.1500	2.0000	85.0000
6902500	0.9600	0.0310	4.4200	2.2400	2.0000	105.0000
6902800	5.2000	0.0450	22.4000	6.6400	1.7500	80.0000
6907200	2.2700	0.0360	2.9600	6.9400	1.3500	70.0000
6908300	1.9700	0.0590	14.9000	4.3500	0.3400	45.0000
6909700	5.7200	0.1200	13.8000	3.3800	0.5000	30.0000
6910250	1.8300	0.0430	11.6000	5.9300	0.5000	30.0000
6918700	2.2200	0.0750	13.5000	3.6000	1.1000	40.0000
6919200	2.1300	0.0540	15.0000	1.6400	1.0000	30.0000
6921740	1.9600	0.0410	6.1700	5.9200	0.7500	30.0000
6925300	4.0300	0.1260	14.2000	6.0000	1.2500	35.0000
6927100	2.2000	0.0320	14.8000	4.5600	2.1200	60.0000
6931500	4.4600	0.0520	11.8000	2.1600	0.7500	60.0000
6935200	3.0000	0.0750	15.0000	4.0000	0.5000	10.0000
7011200	1.4200	0.0440	6.3900	2.5600	2.0000	35.0000
7011500	1.8200	0.0470	11.7000	4.0400	0.5000	30.0000
7015500	0.6400	0.0320	6.3900	4.3900	0.9400	90.0000
7017500	1.8200	0.0600	5.5500	4.0700	1.5600	26.1000
7064300	2.1800	0.0530	13.4000	2.7000	0.7000	60.0000
7064500	2.3600	0.0360	8.2300	2.0200	1.7000	75.0000
7185500	1.7100	0.0480	24.8000	3.5200	1.5000	105.0000
TENN 3312600	3.3000	0.0680	15.4000	5.5000	0.6700	50.0000
3313620	8.7100	0.1090	14.9000	1.4900	0.4000	100.0000

Table D.7 , continued

SAMPLE	PSP	KSAT	RGF	BMSM	KSM	TC
3418900	3.0700	0.1030	10.2000	2.3500	2.0000	190.0000
3420360	2.3100	0.0760	9.2200	3.0400	2.7500	220.0000
3420380	1.5600	0.0340	15.1000	5.0600	1.6000	180.0000
3420400	2.6100	0.0580	10.3000	1.9300	2.8600	275.0000
3430400	1.2700	0.0200	13.3000	3.0700	0.6400	125.0000
3431520	5.8200	0.0770	12.3000	6.5800	0.7500	95.0000
3431580	1.9400	0.0430	8.3900	2.6600	0.7500	150.0000
3431600	2.1400	0.0380	7.3600	3.8300	1.8000	150.0000
3431650	7.7700	0.1280	9.7400	3.4600	0.3100	40.0000
3435020	3.0300	0.0730	15.6000	3.0800	0.7500	140.0000
3435030	2.9900	0.0850	9.3200	1.5000	1.4000	205.0000
3435600	5.7500	0.0970	17.7000	4.9400	0.6500	50.0000
3461200	4.0800	0.0730	22.2000	1.0400	2.3000	190.0000
3469110	3.7500	0.0950	10.4000	1.8000	5.3000	150.0000
3486225	6.3600	0.1560	23.0000	6.2400	0.5500	70.0000
3519610	7.8800	0.1370	13.7000	3.0700	0.9000	90.0000
3519630	7.1000	0.2320	7.3100	3.1200	0.8300	70.0000
3519640	4.0600	0.0920	4.6700	3.6100	4.6700	245.0000
3519650	5.9900	0.1390	13.9000	2.0300	1.5000	90.0000
3535140	4.2600	0.0760	10.6000	5.7400	1.0000	65.0000
3535160	3.4600	0.0570	13.2000	3.1800	3.2000	220.0000
3535180	5.1800	0.0850	7.1500	7.3200	1.7500	160.0000
3538900	2.8300	0.0860	8.6800	6.1500	4.1700	250.0000
3539100	4.0500	0.1350	10.1000	3.2600	1.5700	186.0000
3597300	1.4300	0.0520	9.0900	2.5200	0.9200	120.0000
3597300	2.5100	0.0920	11.1000	3.1700	0.9200	90.0000
3597400	1.9400	0.0290	8.6300	2.5800	0.9200	180.0000
3597450	2.0200	0.0910	16.2000	4.2000	0.5000	40.0000
3597450	5.6700	0.1800	11.7000	1.4200	0.5000	40.0000
3597500	2.0200	0.0300	9.0000	2.9200	1.2500	250.0000
3597550	2.9600	0.0300	10.0000	1.7000	1.0000	85.0000
3597550	4.2600	0.1040	14.2000	1.9700	1.0000	85.0000
3604070	7.3500	0.1450	23.8000	3.8200	1.1000	80.0000
3604080	6.4900	0.1380	25.6000	5.9300	0.9200	50.0000
3604090	6.9100	0.1700	20.7000	5.3600	0.6700	100.0000
3604100	8.0300	0.0480	19.0000	4.8600	1.0300	185.0000
7028935	1.5800	0.0300	29.3000	6.5200	0.4200	85.0000

Table D.6 Error Values and Statistics from Final Calibrations

STATION NO	PK AVAIL	PK USED	VOLUMES,%	ROUTING,%	TOTAL,%	OBS,MEAN	OBS,STDV	SIM,MEAN	SIM,STDV	CORR CO	INTERCEPT	SLOPE
ALABAMA												
02342200	41	41	84.65	29.39	84.92	2.5440	.1820	2.5679	.1443	.662	.635	.743
02343700	33	30	53.30	24.57	104.28	2.7008	.1743	2.7867	.3337	.743	1.205	.537
02362745	67	39	66.69	30.48	65.97	1.8693	.2845	1.8723	.2867	.873	.241	.870
02363055	20	15	71.12	24.62	64.96	1.7293	.2194	1.7640	.3124	.883	.424	.740
02365310	27	14	39.54	18.76	31.81	1.9792	.1082	1.9951	.1311	.928	.297	.843
02371200	42	41	69.11	34.14	75.41	2.2801	.1251	2.2974	.2266	.773	.961	.574
02372410	41	18	51.01	29.74	34.01	1.6255	.0900	1.6443	.1256	.916	.350	.776
02399830	45	45	87.57	21.88	84.26	2.5791	.1466	2.6309	.1518	.637	.931	.626
02400033	61	47	114.23	117.01	77.47	1.9447	.3150	1.9108	.1770	.163	-.255	1.151
02406690	45	26	41.32	30.01	31.59	2.1001	.0670	2.1097	.0904	.694	.476	.770
02407900	39	38	62.40	29.44	73.52	2.7569	.1892	2.7717	.1795	.763	.587	.783
02408340	25	24	64.36	34.13	55.56	2.4566	.1409	2.4800	.1628	.829	.545	.771
02410000	50	50	74.95	24.46	75.57	2.5233	.2059	2.4818	.2619	.613	.735	.721
02417320	35	22	75.41	27.73	58.91	1.5527	.2027	1.6077	.3786	.948	.438	.693
02413400	43	43	42.73	23.30	46.59	2.6951	.0689	2.7297	.0970	.727	.864	.663
02414800	46	45	68.19	57.28	54.06	2.7011	.0927	2.7198	.0680	.722	.696	.741
02417400	44	41	105.20	28.49	142.03	1.9821	.1447	2.4028	.1369	.741	.152	.762
02421200	33	30	64.22	49.27	59.21	2.4293	.1407	2.4676	.1751	.820	.615	.735
02427013	64	41	60.83	25.91	62.34	2.6166	.1697	2.7240	.2598	.894	.648	.723
02437800	40	38	79.57	29.45	61.58	2.6398	.0983	2.0593	.0681	.627	.685	.754
02437900	43	42	96.00	21.97	91.77	2.5343	.1109	2.6340	.2073	.661	1.761	.483
02449460	38	37	42.20	21.01	38.70	3.1353	.0701	3.1674	.1048	.869	.685	.710
02450200	37	36	92.21	35.51	65.48	2.7517	.1590	2.7700	.1705	.784	.654	.757
02451550	29	27	72.45	34.39	74.98	1.8423	.0984	1.8816	.2348	.802	.865	.519
02451750	30	30	77.97	49.46	62.64	2.3748	.2035	2.3494	.1549	.825	.154	.945
02453900	35	28	40.97	15.57	37.87	2.3263	.1018	2.2953	.0606	.875	-.276	1.134
02462600	39	39	67.97	62.54	72.61	2.6359	.2003	2.5590	.1142	.775	.008	1.027
02465205	46	45	72.24	24.57	74.26	1.9680	.2672	2.0004	.3572	.866	.467	.750
02471026	30	22	61.61	38.77	74.21	2.0631	.1622	2.0786	.3145	.858	.782	.616
02479583	56	30	64.65	42.46	61.43	1.8660	.0790	2.0120	.1519	.860	.619	.620
03574405	29	17	31.85	29.81	26.87	2.3672	.0598	2.4176	.0915	.940	.550	.759
03565380	64	41	67.43	70.94	74.94	2.3475	.1542	2.1245	.2223	.906	.745	.754
GEORGIA												
02189020	21	20	55.53	25.14	41.75	2.7546	.0317	2.7156	0828	.829	1.364	.512
02189030	22	22	36.99	25.28	25.93	1.8153	.0603	1.6058	.0648	.928	.402	.783
02191270	15	15	50.99	21.70	50.18	2.5212	.1244	2.4192	.1179	.661	.381	.865
02191280	15	14	35.71	37.79	27.72	1.7741	.0665	1.8140	.0552	.905	-.028	.993
02191600	15	15	74.77	35.64	54.20	2.6173	.1032	2.5654	.2355	.932	1.035	.617
02191750	15	15	36.34	27.42	25.59	2.6834	.0367	2.6702	.0299	.825	.240	.915
02192300	18	18	29.64	34.19	26.80	1.2974	.1179	1.2948	.1099	.942	.034	.976
02192400	24	12	44.48	16.30	38.58	2.5493	.0691	2.4595	.0923	.893	.649	.773
02192420	18	17	56.83	31.68	58.22	2.0080	.0732	1.8796	.1179	.805	.816	.634
02193600	21	20	31.78	24.64	27.58	2.4329	.0271	2.4540	.0427	.826	.819	.658
02201110	12	12	53.41	35.69	42.66	2.2957	.0610	2.2801	.0607	.734	.613	.738
02201160	32	31	65.33	57.64	66.60	2.3246	.0896	2.1606	.1301	.806	.880	.669
02201620	15	15	97.82	28.65	76.05	2.1566	.0234	1.9719	.0784	.500	1.618	.273
02202910	16	16	56.23	20.66	54.08	1.8261	.1174	1.8711	.1472	.822	.453	.734
02202450	12	12	45.39	23.44	38.00	1.6760	.0245	1.8535	.0236	.469	.992	.478
02208200	16	16	24.64	32.09	60.37	1.9855	.0729	1.8628	.1350	.812	.874	.597
02211459	19	19	46.23	19.76	46.49	2.1755	.0579	2.1267	.1005	.803	.879	.610
02215260	17	17	65.17	21.60	51.76	2.1243	.0767	2.0049	.1419	.892	.809	.656
02216610	25	25	50.98	32.31	43.40	2.1426	.1092	2.1621	.0918	.838	.167	.914

Table D.8 , continued

STATION NO	PK AVAIL	PK.USED	VOLUMES.%	ROUTING.%	TOTAL.%	OBS.MEAN	OBS.STDV	SIM.MEAN	SIM.STDV	CORR CO	INTERCEPT	SLOPE
02217250	17	15	42.22	25.75	27.45	1.8927	.0664	1.8385	.0731	.922	.276	.879
02217400	15	14	26.14	26.41	29.48	2.4620	.0594	2.4767	.0517	.860	.179	.922
02217660	21	20	62.33	36.00	61.39	2.0411	.0472	1.8781	.0674	.686	.963	.574
02218100	23	21	34.01	20.07	27.40	2.2893	.0668	2.2509	.0560	.903	.070	.986
02223700	13	13	60.92	28.39	49.67	1.9441	.0488	2.0145	.0857	.744	.814	.561
02224200	12	12	62.58	20.63	57.09	2.5510	.1166	2.4366	.2050	.902	.895	.680
02225330	15	15	52.01	21.63	41.65	2.2719	.0463	2.3591	.0462	.746	.510	.747
02315900	19	19	43.10	26.77	37.26	1.7070	.0555	1.8114	.0627	.794	.435	.747
02316220	13	13	83.36	34.19	76.43	1.7621	.0683	1.5464	.1262	.769	.887	.566
02316260	24	24	47.40	31.19	30.66	2.1263	.0724	2.0885	.0666	.887	.195	.925
02317710	16	16	70.04	71.21	22.47	1.6957	.0254	1.6686	.0321	.842	.419	.750
02317760	16	16	29.63	19.99	34.61	2.2820	.0349	2.3568	.0339	.765	.453	.776
02317765	17	16	52.44	27.88	58.04	1.6020	.0568	1.4784	.1125	.794	.768	.564
02317770	20	19	32.51	21.00	29.79	2.1610	.0420	2.1971	.0354	.809	.223	.882
02317775	19	19	47.08	23.08	43.02	1.7371	.0614	1.8134	.0729	.860	.406	.734
02317780	17	17	43.52	23.38	45.42	1.7955	.0352	1.9008	.0491	.707	.658	.598
02317795	20	20	43.10	25.42	45.68	2.3127	.0483	2.2114	.0762	.670	.302	.909
02317845	27	27	37.78	21.30	31.70	2.0736	.0420	1.9607	.0555	.860	.556	.768
02317905	18	18	63.14	34.51	48.07	2.3685	.0666	2.2186	.0737	.871	.531	.828
02317910	32	31	48.79	17.01	44.57	2.0660	.0411	1.9789	.0886	.877	.904	.597
02318015	15	15	43.74	28.72	37.32	1.9367	.1035	1.9766	.0819	.879	-.016	.968
02318020	21	21	22.88	22.15	27.71	1.7611	.0412	1.7463	.0241	.814	-.100	1.065
02327350	27	13	42.14	14.13	39.56	2.0920	.0466	2.2152	.0300	.887	-.369	1.106
02327400	18	18	41.96	22.29	31.07	2.2709	.0383	2.2147	.0476	.799	.633	.717
02346193	23	22	32.07	23.05	34.31	2.6270	.0806	2.5652	.0664	.884	.128	.974
02346210	27	26	43.18	22.61	34.42	2.5502	.0842	2.5024	.1085	.907	.550	.799
02346217	15	15	41.75	35.06	40.20	2.0900	.0755	2.0804	.0378	.789	.231	1.116
02350520	24	24	34.19	26.15	24.78	2.3103	.0355	2.2756	.0436	.876	.511	.791
02381100	28	21	62.97	56.72	36.58	2.0570	.0160	2.0154	.0398	.660	1.716	.418
02381600	18	16	55.26	25.00	28.22	2.5142	.0173	2.5361	.0346	.769	1.134	.544
02381900	16	16	47.82	50.43	29.31	2.5676	.0195	2.5129	.0274	.737	1.032	.623
02382200	12	12	32.62	21.48	26.56	2.4562	.0625	2.4454	.0530	.874	.135	.949
02382900	25	25	47.30	38.13	32.46	2.6269	.0281	2.6197	.0400	.729	1.026	.611
02383000	18	18	20.99	16.46	27.89	2.4841	.0647	2.4936	.0606	.923	.105	.956
02387300	22	22	39.26	28.66	22.43	1.6864	.0175	1.6411	.0191	.801	.429	.766
02387560	23	23	37.69	23.94	30.35	2.3849	.0157	2.4183	.0394	.790	1.179	.499
02387700	17	17	80.35	61.69	31.72	2.7022	.0310	2.6838	.0311	.708	.804	.707
02387800	18	18	29.73	26.76	23.14	2.4976	.0728	2.4902	.0637	.930	.022	.994
02388200	18	18	38.41	31.47	26.14	2.6258	.0400	2.6507	.0527	.882	.395	.842
02388400	22	21	56.77	31.87	50.71	2.3901	.0477	2.2778	.0814	.765	1.045	.586
02397750	26	25	31.73	23.40	20.22	2.6117	.0415	2.6266	.0485	.920	.376	.851
03566660	26	14	28.96	15.67	24.18	2.4296	.0351	2.3984	.0283	.849	.164	.945
03566687	14	14	66.39	60.87	36.41	2.4204	.1073	2.3693	.0793	.895	-.041	1.041
ILLINOIS												
03338100	19	10	30.25	19.60	35.26	2.0147	.1235	2.0279	.1112	.906	.079	.954
03344250	6	6	44.67	24.98	32.64	1.2461	.0686	1.2482	.0731	.863	.203	.836
03360300	11	9	30.66	15.44	35.68	1.5663	.0265	1.5434	.0578	.785	.716	.551
03380450	8	7	29.77	26.93	24.36	2.1503	.0564	2.1177	.0494	.908	.094	.971
03381600	7	7	31.94	20.58	16.58	1.6866	.0434	1.6645	.0351	.946	-.064	1.052
03382025	12	6	13.75	13.45	8.30	2.1452	.0599	2.1407	.0560	.956	-.046	1.024
05418800	11	9	78.53	61.43	42.27	2.1912	.1195	2.2180	.1393	.882	.380	.817
05437600	8	4	106.15	17.30	101.10	2.4332	.0069	2.5983	.1220	.031	2.476	.003
05438850	12	9	43.59	30.70	46.50	1.9912	.1412	2.0297	.1458	.872	.249	.858
05439550	17	12	73.05	31.37	66.30	2.2398	.0383	2.2896	.1232	.661	1.396	.368

Table D.8 , continued

STATION NO	PK AVAIL	PK USED	VOLUMES.%	ROUTING.%	TOTAL.%	OBS.MEAN	OBS.STDV	SIM.MEAN	SIM.STDV	CORR CO	INTERCEPT	SLOPE
05448050	7	6	41.38	26.44	19.60	1.6924	.0556	1.6903	.1308	.980	.276	.838
05469750	11	7	46.62	19.94	47.02	1.6259	.1710	1.5495	.1294	.898	.027	1.032
05495200	28	17	42.83	20.43	38.29	2.3820	.1129	2.3692	.1312	.894	.405	.929
05502120	22	14	34.72	35.06	22.54	2.3755	.0557	2.3667	.0568	.913	.113	.956
05527050	7	6	42.28	15.45	44.28	1.7672	.0187	1.8121	.0347	.402	1.233	.295
05536265	7	7	33.74	20.51	50.74	1.8374	.0123	1.9083	.0857	.887	1.193	.338
05541750	19	12	69.92	60.18	26.26	1.8603	.0315	1.8726	.0383	.823	.463	.746
05551600	11	6	65.27	27.34	53.39	1.8904	.0501	1.9463	.1024	.741	.881	.518
05554600	28	13	31.35	22.08	35.68	1.7057	.0187	1.7318	.0283	.526	.962	.429
05555400	10	9	23.72	27.05	34.21	1.3564	.1170	1.3451	.0836	.907	-.087	1.073
05557100	17	12	69.91	35.39	68.89	1.6345	.0374	1.8564	.0496	.106	1.664	.092
05558050	27	12	30.43	30.41	35.02	1.2823	.0488	1.2785	.0340	.743	.145	.890
05558075	25	9	30.36	22.16	37.81	1.7302	.1379	1.7356	.1072	.902	-.044	1.023
05566000	13	9	57.72	9.67	58.92	2.0020	.0216	2.1192	.1237	.846	1.333	.353
05572100	10	10	41.63	27.21	37.68	1.4517	.0296	1.4474	.0491	.695	.669	.540
05577520	50	48	53.43	27.99	48.03	1.8456	.1190	1.8382	.1007	.818	.211	.889
05577700	22	15	95.36	22.47	65.79	2.0642	.1333	2.0162	.1152	.560	.870	.602
05586500	12	10	57.53	15.99	68.68	2.0632	.0850	2.0040	.1407	.692	.986	.538
05587850	21	11	70.63	24.52	85.06	1.2889	.1153	1.2706	.1638	.623	.625	.523
05591500	21	15	34.52	31.15	45.92	2.2112	.0762	2.2119	.0680	.742	.474	.785
05594200	10	8	22.47	21.63	22.18	2.1827	.1347	2.1506	.1428	.971	.155	.943
05595550	19	17	27.77	17.90	23.49	2.3345	.0180	2.3373	.0268	.783	.834	.642
05596100	9	8	29.38	16.81	18.89	2.3047	.0501	2.2622	.0383	.953	-.160	1.090
05599640	9	5	33.65	17.00	22.83	2.2534	.0347	2.3307	.0420	.884	.481	.804
MISSISSIPPI												
02429980	32	19	51.77	26.95	41.59	1.9360	.0387	2.0037	.0746	.806	.774	.581
02435300	6	6	16.22	24.44	30.77	1.9307	.0289	1.8894	.0145	.678	.121	.958
02435400	28	28	60.92	19.42	53.60	1.8472	.0548	1.9222	.1054	.763	.789	.550
02437550	51	42	52.58	24.08	52.75	1.7703	.0566	1.8826	.0968	.795	.627	.607
02440020	30	15	57.02	22.86	60.48	2.1617	.0857	2.2576	.1743	.844	.795	.606
02441220	32	23	47.33	21.74	45.97	1.8221	.0466	1.8400	.0950	.783	.616	.655
02447340	9	9	50.84	14.40	44.52	1.7070	.0546	1.7057	.0537	.677	.542	.683
02475220	9	8	31.88	25.16	29.71	1.6359	.0899	1.6654	.0743	.894	.192	.867
02477090	20	19	45.63	29.43	58.60	1.9678	.1090	2.0277	.0690	.726	.339	.803
02477099	7	7	32.33	36.78	17.70	2.1807	.0905	2.1773	.0746	.989	-.133	1.090
02478600	12	11	28.56	20.94	45.77	2.1095	.0609	2.1530	.0409	.373	1.780	.153
02479165	16	15	44.55	31.17	44.16	1.5399	.0439	1.5723	.0524	.653	.601	.597
02481505	18	12	49.38	37.86	33.23	2.1301	.0366	2.1348	.0433	.751	.656	.691
02485700	11	11	70.61	43.47	46.40	1.9549	.1059	2.0133	.0718	.820	-.051	.996
02485960	9	9	33.06	18.30	27.17	2.2452	.0458	2.2157	.0371	.851	.151	.945
02485900	3	3	96.59	44.51	137.69	2.4867	.0562	2.1235	.0110	.806	6.354	-1.821
02487670	10	8	62.78	27.47	62.15	1.9145	.0403	1.9535	.0553	.338	1.351	.289
02487710	18	15	51.30	9.33	48.60	2.0547	.0210	2.0106	.0590	.574	1.367	.342
02488550	11	9	71.60	25.99	64.31	1.7561	.1393	1.7927	.1294	.743	.405	.771
02488600	14	12	65.75	24.42	52.65	1.3219	.0076	1.3183	.0447	.112	1.261	.046
02489030	26	26	46.20	19.59	45.33	2.1326	.0693	2.1419	.0561	.714	.434	.793
02489165	5	4	52.21	28.60	39.13	2.0696	.0308	2.0945	.0153	.556	.719	.884
0702.9252	8	7	31.96	37.25	35.84	2.2527	.0310	2.2816	.0558	.773	.938	.576
07267200	12	10	28.99	30.08	23.09	1.6062	.0387	1.5996	.0458	.866	.303	.815
07277550	25	22	38.18	36.23	33.20	2.0216	.0542	1.9711	.0540	.838	.366	.840
07282300	22	22	69.35	48.26	50.65	1.9078	.0882	1.8986	.0353	.714	-.233	1.127
07285700	25	21	51.06	44.51	47.36	2.6317	.0743	2.7220	.0919	.815	.635	.734
07287140	15	12	68.78	27.97	55.88	1.4267	.1114	1.4696	.1066	.762	.287	.779
07287520	19	19	49.76	21.22	48.44	2.5390	.0273	2.6059	.0767	.734	1.397	.438

Table D.8 , continued

STATION NO	PK AVAIL	PK USED	VOLUMES.%	ROUTING.%	TOTAL.%	OBS.MEAN	OBS.STDV	SIM.MEAN	SIM.STDV	CORR CO	INTERCEPT	SLOPE
07287520	9	9	25.75	20.59	33.80	2.4830	.0770	2.4632	.0833	.873	.416	.839
07288568	13	10	20.42	17.73	19.58	1.1493	.0587	1.1693	.0839	.968	.203	.809
07289640	17	16	26.46	33.39	27.44	1.7952	.0852	1.8053	.0715	.915	-.009	.999
07289646	13	13	20.25	41.68	44.95	1.9508	.0676	2.0122	.0621	.753	.371	.765
07290220	17	14	41.64	47.27	35.25	1.7375	.0649	1.7143	.0642	.860	.040	.990
07290525	23	23	69.06	27.54	52.06	2.2315	.0609	2.2549	.0839	.686	.913	.585
07290910	39	39	56.69	19.33	59.78	2.4620	.0790	2.4980	.1298	.742	1.017	.579
07294400	13	12	43.34	25.39	34.89	1.9218	.1057	1.9263	.1020	.894	.170	.909
07294400	6	6	28.09	17.32	31.62	2.1677	.0373	2.1146	.0429	.869	.573	.354
07373550	4	4	13.92	31.28	30.21	2.2217	.0135	2.2373	.0005	.465	7.404	-2.318
07375235	21	19	63.84	25.80	54.30	2.1295	.0911	2.1505	.0951	.728	.597	.713
07376665	27	24	67.74	29.00	63.94	1.6494	.0921	1.7018	.1179	.692	.609	.611
07376665	14	13	27.89	14.45	25.67	1.9031	.0188	1.8949	.0124	.625	.445	.770
07376760	25	21	52.85	27.15	41.98	2.1269	.0306	2.0978	.0367	.556	1.084	.494
MISSOURI												
05497700	15	12	158.02	37.60	149.51	2.0699	.0464	1.9141	.2292	.183	1.932	.082
05507700	21	21	93.88	32.68	98.36	1.9658	.1520	2.0381	.1096	.479	.815	.565
05503000	24	22	56.54	19.90	47.10	2.5017	.1759	2.4912	.2008	.898	.407	.841
06015550	11	9	38.38	28.89	20.05	2.0381	.0655	2.0454	.0632	.942	.074	.960
06216000	28	27	57.34	20.99	64.52	2.7434	.1364	2.7539	.1060	.718	.500	.815
06820000	31	28	104.26	26.83	105.28	2.5677	.1412	2.6644	.1803	.526	1.347	.466
06897700	26	25	79.78	22.75	69.98	2.3153	.0624	2.3814	.0906	.511	1.306	.424
06902500	33	24	87.74	24.44	69.54	2.5292	.0553	2.4456	.1041	.572	1.510	.417
06902800	12	12	162.45	42.35	113.98	1.6388	.0789	1.7030	.1931	.387	1.217	.248
06907200	15	13	69.95	30.90	46.04	2.2360	.0487	2.2668	.0888	.767	.949	.568
06908200	17	16	46.32	19.00	52.28	2.2130	.2336	2.2171	.2508	.902	.282	.871
06909700	19	17	82.40	33.86	65.30	2.2567	.0774	2.3202	.0922	.604	.974	.554
06910250	12	12	66.36	19.72	60.15	1.9764	.0782	1.9649	.1269	.722	.864	.566
06918700	18	18	63.64	29.96	56.30	2.2976	.0828	2.3711	.1294	.770	.836	.616
06919200	13	10	31.66	26.48	35.12	1.5287	.0643	1.5054	.0371	.814	-.084	1.072
06921740	34	31	56.39	17.61	54.86	2.5138	.0663	2.5650	.0781	.660	.953	.608
06925000	21	20	56.82	36.14	50.50	1.9765	.1417	2.0093	.1487	.850	.309	.830
06927100	15	9	56.26	57.41	55.39	1.7275	.0581	1.7511	.0584	.547	.781	.546
06931500	46	45	83.02	25.36	83.38	2.8515	.1052	2.0577	.0971	.462	1.477	.481
06935800	40	39	97.07	47.31	89.47	2.2147	.0619	2.2188	.2333	.697	1.299	.413
07011200	9	7	45.87	27.69	46.44	2.0267	.0505	2.0873	.0513	.655	.673	.650
07011500	32	32	36.46	29.92	37.00	2.3364	.1176	2.3220	.0941	.869	.029	.994
07015500	21	21	28.66	23.29	36.42	1.8010	.0250	1.7602	.0373	.653	.860	.534
07017500	28	20	41.83	26.31	28.44	2.7467	.0123	2.7451	.0237	.617	1.528	.444
07064300	19	17	50.74	53.15	45.52	1.8739	.0902	1.9094	.0881	.801	.326	.811
07064500	33	30	55.87	32.06	48.53	3.0675	.0886	3.1040	.0729	.749	.524	.826
07185500	30	27	70.30	37.65	50.89	2.9942	.0854	2.6712	.0887	.740	.774	.776
TENNESSEE												
03313600	25	25	45.80	25.66	45.35	1.9630	.0842	1.9854	.0643	.764	.226	.875
03313620	16	9	28.89	15.14	19.88	2.4672	.1227	2.4641	.1089	.970	-.069	1.029
03418900	12	11	53.69	19.32	54.55	2.1516	.1620	2.0181	.1406	.891	.222	.956
03420360	14	11	52.99	22.82	56.50	2.3351	.1020	2.3525	.0916	.719	.550	.759
03420380	20	16	27.43	20.30	32.04	2.0451	.0954	2.0997	.1027	.921	.181	.888
03420400	23	21	33.20	25.28	45.97	2.7410	.1468	2.7016	.1017	.875	-.082	1.045
03430400	19	19	39.45	22.26	33.32	3.4415	.0211	3.4411	.0435	.731	1.689	.509
03431520	10	10	50.05	16.99	50.41	2.6512	.0732	2.5998	.1184	.804	1.007	.633
03431860	18	17	20.53	17.88	26.40	3.1955	.0538	3.1390	.0444	.905	.068	.996
03431600	31	25	42.91	16.10	38.91	3.3842	.0423	3.3800	.0730	.792	1.348	.603

Table D.8 , continued

STATION NO	PK AVAIL	PK USED	VOLUMES,%	ROUTING,%	TOTAL,%	OBS.MEAN	OBS.STDV	SIM.MEAN	SIM.STDV	CORR CO	INTERCEPT	SLOPE
03431650	15	15	65.40	17.19	76.86	2.3472	.1019	2.2045	.1246	.730	.892	.660
03435020	22	16	27.40	22.56	28.71	2.9828	.1317	2.9861	.1391	.944	.238	.919
03435030	14	4	39.76	58.84	66.12	3.0952	.0928	2.9427	.2472	.959	1.367	.587
03435600	39	38	47.62	54.09	53.74	2.2384	.1774	2.2608	.1479	.851	.131	.932
03461200	12	11	53.39	12.96	57.77	2.5472	.0866	2.6201	.1704	.843	.955	.608
03469110	9	9	33.60	22.84	46.37	1.5571	.1639	1.4954	.2085	.915	.273	.859
03486225	9	9	52.79	28.62	36.21	1.7657	.1925	1.7444	.2470	.954	.296	.842
03519610	19	16	37.67	15.59	43.14	2.1061	.0994	2.1453	.1117	.851	.393	.799
03519630	16	14	36.46	24.27	41.44	1.9866	.1267	1.9980	.1740	.909	.436	.776
03519640	23	7	110.65	21.21	127.89	2.5815	.1727	2.9940	.1523	.861	-.364	.984
03519650	13	13	44.04	26.74	46.43	2.1206	.1582	2.1500	.1809	.892	.327	.834
03535140	13	13	35.76	15.22	37.99	2.3425	.0639	2.3436	.1378	.936	.850	.637
03535160	22	12	60.03	17.88	64.88	2.8181	.1320	2.7771	.2944	.907	1.131	.607
03535180	18	17	43.49	16.72	42.76	2.1931	.1627	2.2593	.2297	.944	.399	.794
03538900	22	20	45.05	28.92	48.24	2.0550	.1637	2.0873	.1646	.878	.227	.876
03539100	20	18	31.12	13.85	28.44	1.6228	.0512	1.6549	.0649	.889	.316	.790
03597300	29	29	63.61	14.09	60.46	2.7498	.1283	2.8483	.1558	.820	.631	.744
03597300	29	29	80.35	13.73	81.65	2.7498	.1283	2.6067	.2717	.843	1.239	.579
03597400	19	15	31.78	15.02	37.60	3.1443	.0661	3.1553	.0542	.799	.362	.882
03597450	27	12	45.45	22.93	30.57	2.2916	.0692	2.3022	.0853	.896	.458	.796
03597450	27	12	133.44	18.56	126.67	2.2916	.0662	1.9072	.2137	.903	1.319	.510
03597500	23	23	31.03	12.22	28.36	3.1069	.1157	3.1818	.1028	.934	.035	.991
03597550	31	11	96.40	21.47	89.13	2.4521	.0579	2.7429	.0274	.604	.046	.877
03597550	31	11	53.33	13.56	59.01	2.4521	.0579	2.3503	.0862	.673	1.156	.551
03604070	8	8	50.38	15.61	41.77	1.9253	.0372	1.6598	.0826	.838	.861	.562
03604080	9	9	56.80	24.27	56.41	1.9911	.2643	1.8411	.3447	.955	.451	.837
03604090	21	10	57.40	25.81	65.58	2.7387	.2211	2.6790	.3147	.866	.749	.743
03604100	16	9	35.01	21.39	40.22	2.9017	.1347	2.9159	.0894	.889	-.282	1.092
07028935	24	23	27.73	15.04	35.54	2.3723	.1170	2.2919	.1098	.928	.177	.958

Table D.9 Observed Distribution of Storm Events Used in Final Calibrations of Sites in Study

STA NO.	#EE	BASIN RESPONSE RO/RF LOW	MED	HIGH	Q/DA LOW	MED	HIGH	AVE PRECIP LOW	MED	HIGH	MODEL INPUT SIF 3HR LOW	MED	HIGH	AMI LOW	MED	HIGH
ALABAMA																
02342200	37	14	19	4	27	7	3	22	14	1	12	14	11	16	14	7
02343700	31	21	9	1	24	6	1	13	13	5	4	11	16	7	9	15
02362745	53	40	8	2	46	5	2	49	3	0	32	17	4	21	20	12
02363055	17	13	3	0	13	4	0	11	6	0	9	4	4	10	4	3
02365310	21	9	8	4	15	5	1	20	1	0	13	3	5	7	8	6
02371200	41	37	4	0	39	1	1	27	10	4	9	18	14	14	11	16
02372510	39	30	6	0	35	2	0	36	2	0	26	9	4	17	11	11
02399800	38	17	16	5	33	5	0	33	5	0	24	10	4	9	20	9
02400033	50	39	4	2	43	5	2	44	5	1	34	12	4	10	26	14
02400690	36	22	6	3	36	0	0	33	0	1	27	6	3	7	15	14
02407900	37	19	15	3	27	7	3	29	7	1	10	14	13	12	16	9
02408340	25	13	7	5	20	5	0	21	4	0	12	8	5	7	12	6
02410000	45	27	15	1	20	23	2	16	16	13	7	15	23	16	17	12
02412320	27	22	4	1	24	2	1	22	4	1	22	1	4	19	5	3
02413400	37	14	18	5	15	27	0	15	17	5	11	15	11	11	8	16
02414500	39	24	11	4	18	20	1	23	12	4	13	16	8	10	17	17
02417400	34	30	4	0	14	10	2	11	17	6	10	15	9	12	6	16
02421300	30	26	2	2	26	2	0	20	4	6	7	14	9	8	10	12
02427013	57	9	12	33	9	24	24	36	7	13	23	9	25	19	14	24
02437800	37	10	10	17	26	10	1	25	9	3	11	12	14	8	11	18
02437900	40	23	13	3	36	2	0	31	8	1	19	11	10	4	18	16
02449400	33	4	5	21	6	22	2	18	7	5	11	9	10	7	13	10
02450200	34	6	12	15	24	10	0	29	5	0	15	10	9	11	13	10
02451550	24	21	3	0	17	6	1	7	12	5	8	6	10	6	8	10
02451750	25	12	7	6	7	10	8	12	6	7	4	13	8	3	7	15
02453900	34	9	12	13	27	7	0	28	5	1	15	17	2	6	18	10
02462600	33	8	13	12	15	14	4	23	7	3	7	15	11	6	15	12
02465205	41	31	7	1	32	8	1	30	11	0	24	10	7	17	9	15
02471026	29	22	4	1	22	5	2	18	6	5	13	9	7	10	7	12
02479563	48	40	1	1	47	1	0	36	4	2	19	17	12	9	20	19
03574405	25	8	7	4	18	5	2	22	3	0	15	6	4	3	11	11
03585380	48	27	15	5	37	11	0	33	10	5	21	13	14	11	21	16
GEORGIA																
02189070	18	2	8	8	7	11	6	10	6	2	9	7	2	3	6	9
02189030	20	0	7	13	2	11	7	8	6	4	11	4	5	3	11	6
02191270	14	5	8	1	10	4	0	10	3	1	8	3	3	3	6	5
02191280	12	4	3	5	2	6	4	4	3	5	5	7	0	6	3	3
02191600	13	5	5	3	6	6	1	6	2	5	5	3	5	3	5	5
02191750	15	2	9	4	13	2	0	11	4	0	13	0	2	3	7	5
02192300	15	1	6	8	0	8	7	5	5	5	8	4	3	5	9	1
02192400	21	8	10	3	12	9	0	10	9	2	10	7	4	6	11	4
02192420	16	8	6	2	4	9	3	2	9	5	5	5	6	6	6	4
02193600	20	0	14	6	6	12	8	2	12	6	4	10	6	5	7	8
02201110	17	5	3	4	11	1	0	11	1	0	3	5	4	3	6	3
02201160	28	12	11	5	25	2	1	24	2	2	13	12	3	9	14	5
02201830	13	3	9	1	13	0	0	11	2	0	5	5	3	4	3	6
02202910	16	11	3	2	13	2	1	9	3	4	4	5	7	4	6	6
02202950	12	1	4	7	10	2	0	7	5	0	6	3	3	3	4	5
02208200	14	9	2	3	5	8	1	3	5	6	4	6	4	4	3	7
02211459	17	12	4	1	9	8	0	9	4	4	9	5	3	3	9	5
02215280	17	4	11	2	12	5	0	14	0	3	6	7	4	4	6	7
02216610	23	7	10	6	19	2	2	18	3	2	11	7	5	5	10	8
02217250	14	4	7	3	1	9	4	0	8	6	3	6	5	4	6	4

Table D.9 , continued

STA NO.	#FE	BASIN RESPONSE RO/RF LOW	MED	HIGH	Q/DA LOW	MED	HIGH	AVE PRECIP LOW	MED	HIGH	MODEL INPUT SIF 3HR LOW	MED	HIGH	AMI LOW	MED	HIGH
02217400	13	3	8	2	3	9	1	3	8	2	6	5	2	3	7	3
02217660	18	9	8	1	3	13	2	4	9	5	7	8	3	2	9	7
02218100	19	6	5	8	6	11	2	7	8	4	9	5	5	3	11	5
02223700	13	5	7	1	10	3	0	8	2	3	5	3	5	2	4	7
02224220	12	4	4	4	12	0	0	11	1	0	4	5	3	5	4	3
02225330	15	4	8	3	15	0	0	15	0	0	7	7	1	4	2	9
02315900	19	6	8	5	16	3	0	15	4	0	8	8	3	4	8	7
02316220	12	5	3	4	9	3	0	9	2	1	4	4	4	3	6	3
02316260	23	1	1	21	22	1	0	22	1	0	16	3	4	2	13	8
02317710	16	5	5	6	14	2	0	9	6	1	5	4	7	1	7	8
02317760	14	2	8	4	14	0	0	14	0	0	6	5	3	4	6	4
02317765	15	7	6	2	13	1	1	11	3	1	4	9	2	2	5	8
02317770	18	2	13	3	18	0	0	18	0	0	8	7	3	7	6	5
02217775	16	4	9	3	12	4	0	9	5	2	8	6	2	3	5	8
02317780	16	2	11	3	6	10	0	6	8	2	3	8	5	2	6	8
02317795	20	1	14	5	19	1	0	20	0	0	11	4	5	8	6	6
02317845	25	2	10	13	16	9	0	20	5	0	9	10	6	5	9	11
02317905	18	2	8	8	11	7	0	16	2	0	3	8	7	6	5	7
02317910	30	1	16	13	20	10	0	21	9	0	12	7	11	8	11	11
02318015	15	1	5	9	10	4	1	12	2	1	7	3	5	2	5	8
02318020	20	0	0	20	0	12	8	13	6	1	6	8	6	4	5	11
02327350	26	1	9	16	17	9	0	18	6	2	15	5	6	8	6	12
02327450	18	4	10	4	14	4	0	11	7	0	5	5	8	4	7	7
02346193	21	1	12	8	3	15	3	11	6	4	8	7	6	6	9	6
02346210	26	6	13	7	19	6	1	21	4	1	14	9	3	7	11	8
02346217	15	12	3	0	11	4	0	8	6	1	4	9	2	3	8	4
02350520	22	0	8	14	14	8	0	21	1	0	13	6	3	5	7	10
02361100	19	17	2	0	17	2	0	8	6	5	9	9	1	2	6	11
02381600	18	14	4	0	18	0	0	17	1	0	8	8	2	3	5	10
02381900	16	4	8	4	1	15	0	7	8	1	4	9	3	2	11	3
02382600	12	0	3	9	5	7	0	8	3	1	6	3	3	1	6	5
02382960	25	9	12	4	24	1	0	20	4	1	13	12	0	5	11	9
02383000	18	2	9	7	13	5	0	11	7	0	11	6	1	5	8	5
02387300	21	1	2	18	0	9	12	4	10	7	9	8	4	7	5	9
02387560	22	9	12	1	14	8	0	11	9	2	8	12	2	4	12	6
02387700	17	4	0	13	13	4	0	12	4	1	9	3	5	4	4	9
02387600	18	0	3	15	12	4	2	14	3	1	11	3	4	1	8	9
02388200	17	0	9	8	10	7	0	12	4	1	7	7	3	3	4	10
02388400	20	7	9	4	11	9	0	4	12	4	9	6	5	5	6	9
02397750	21	0	2	19	12	9	0	19	2	0	9	9	3	4	12	5
03566660	22	0	4	18	15	7	0	17	4	1	17	5	0	4	10	8
03566687	14	2	3	9	8	5	1	11	0	3	7	4	3	2	1	11
ILLINOIS																
03337100	16	6	6	4	13	3	0	12	4	0	10	4	2	3	6	7
03344250	6	0	1	5	0	3	3	3	0	3	3	1	2	1	2	3
03360300	7	1	3	3	0	0	7	5	1	1	3	2	2	3	2	2
03380450	6	0	3	2	0	2	4	2	3	1	2	3	1	2	3	1
03381600	7	4	1	2	0	1	6	4	2	1	2	4	1	4	1	2
03382025	11	1	0	10	1	6	4	8	2	1	7	2	2	3	6	2
05419800	10	3	4	2	1	7	2	7	0	3	6	1	3	3	2	5
05437600	8	6	1	1	4	4	0	4	1	3	3	1	4	5	1	2
05438650	10	5	3	1	6	4	0	7	3	0	4	2	4	3	2	5
05439550	15	8	5	2	6	9	0	12	3	0	5	6	4	4	8	3
05448050	7	4	3	0	1	4	2	2	1	4	0	3	4	1	4	2
05469750	7	2	3	2	1	3	3	3	2	2	1	3	3	3	1	3

Table D.9 , continued

STA NO.	#FE	BASIN RESPONSE RO/RF LOW	MED	HIGH	Q/DA LOW	MED	HIGH	AVE PRECIP LOW	MED	HIGH	MODEL INPUT SIF 3HR LOW	MED	HIGH	AMI LOW	MED	HIGH
05495200	17	4	8	5	0	10	7	15	2	0	6	6	5	8	4	5
05502120	16	2	5	8	0	6	10	12	4	0	6	5	5	8	2	6
05527050	7	1	2	4	5	2	0	6	1	0	7	0	0	4	2	1
05536265	7	1	6	0	7	0	0	7	0	0	7	0	0	3	2	2
05541750	14	7	7	0	14	0	0	14	0	0	8	5	1	6	7	1
05551800	10	3	2	5	2	6	2	8	1	1	8	0	2	0	8	2
05554600	25	0	1	15	0	8	17	22	2	1	21	1	3	6	6	13
05555400	7	5	1	1	1	5	1	4	2	1	4	2	1	4	3	0
05557100	15	6	5	2	0	8	7	12	3	0	10	3	2	4	5	6
05558050	22	4	9	9	0	1	21	15	6	1	7	11	4	5	9	8
05558075	22	4	13	5	0	13	9	18	2	2	9	8	5	5	11	6
05566000	13	7	5	1	13	0	0	12	1	0	7	5	1	7	3	3
05572100	9	1	4	4	0	2	7	8	0	1	7	1	1	1	1	7
05577520	39	36	3	0	27	11	1	39	0	0	34	5	0	22	14	3
05577700	20	12	4	4	12	5	3	14	5	1	5	9	6	4	12	4
05586500	8	7	1	0	2	6	0	4	4	0	1	5	2	3	2	3
05587850	16	13	1	1	11	4	1	15	0	1	13	1	2	6	7	3
05591500	18	5	10	3	17	1	0	18	0	0	10	6	2	10	4	4
05594200	6	3	0	3	4	1	1	5	1	0	5	0	1	4	2	0
05595550	16	1	6	9	0	3	13	9	5	2	7	8	1	5	4	7
05596100	6	1	1	4	0	4	2	3	2	1	1	4	1	1	2	3
05599640	7	3	1	3	0	0	7	3	0	4	2	2	3	3	2	2

MISSISSIPPI

STA NO.	#FE	RO/RF LOW	MED	HIGH	Q/DA LOW	MED	HIGH	AVE PRECIP LOW	MED	HIGH	SIF 3HR LOW	MED	HIGH	AMI LOW	MED	HIGH
02429980	26	12	8	6	24	2	0	15	7	4	14	8	4	7	11	8
02435300	6	0	0	6	0	0	6	3	3	0	3	3	0	4	1	1
02435400	26	4	14	8	9	16	1	8	11	7	9	9	8	7	7	12
02437550	33	11	14	8	8	23	2	16	12	5	11	12	10	16	5	12
02440020	26	12	7	7	8	11	7	16	5	5	17	6	3	7	13	6
02441220	27	0	8	19	2	21	4	20	5	2	18	7	2	6	11	10
02447340	9	0	3	6	5	4	0	4	4	1	2	2	5	5	2	2
02475220	9	1	7	1	0	7	2	2	2	5	1	2	6	3	2	4
02477090	18	1	2	15	3	9	6	13	1	4	7	9	2	10	5	3
02477090	6	0	0	6	0	0	6	2	1	3	0	3	3	2	2	2
02478600	10	0	2	8	0	9	1	6	3	1	5	3	2	3	4	3
02479365	16	0	6	10	0	15	1	4	6	4	2	7	7	9	4	3
02481505	16	3	6	7	12	4	0	12	4	0	6	4	6	3	9	4
02485760	10	4	4	2	1	4	5	7	1	2	7	1	2	4	4	2
02485900	8	0	2	6	1	6	1	5	1	2	0	3	5	4	3	1
02485900	3	0	0	3	0	2	1	0	1	2	0	3	0	1	1	1
02487670	10	5	5	0	4	6	0	2	5	3	3	4	3	1	5	4
02487710	14	0	4	10	1	12	1	6	7	1	5	4	5	3	6	5
02488550	10	6	1	3	3	4	3	5	4	1	3	1	6	1	2	7
02488650	13	6	5	2	3	10	0	7	6	0	6	7	0	4	4	5
02489030	23	5	10	8	4	13	6	6	8	9	7	9	7	8	9	6
02499160	5	3	0	2	1	3	1	1	3	1	3	2	0	2	1	2
07029152	6	4	3	1	0	7	1	4	4	0	3	5	0	3	3	2
07267200	12	0	2	10	0	9	3	8	3	1	5	6	1	3	8	1
07277550	22	0	3	16	0	6	16	14	6	2	13	7	2	8	7	7
07282300	22	10	5	7	2	12	8	7	11	4	5	13	4	8	5	9
07285700	24	1	9	13	1	10	13	12	7	5	10	7	7	10	9	5
07287140	15	1	3	7	5	7	3	10	2	3	12	1	2	4	7	4
07287520	19	3	7	9	0	10	9	9	7	3	7	7	5	8	6	5
07287520	8	0	2	6	0	4	4	4	1	3	4	3	1	1	4	3
07288568	12	0	1	9	4	8	0	6	4	2	6	4	2	4	2	6
07289640	14	0	3	11	0	7	7	7	4	3	6	2	6	10	0	4

Table D.9 , continued

STA NO.	NFE	BASIN RESPONSE RO/RF LOW	MED	HIGH	Q/DA LOW	MED	HIGH	AVE PRECIP LOW	MED	HIGH	MODEL INPUT SIF 3HR LOW	MED	HIGH	AMI LOW	MED	HIGH
07289640	11	0	0	11	0	3	8	6	2	3	4	4	3	4	6	1
07290220	17	0	4	13	1	8	8	10	3	4	4	6	7	6	8	3
07290525	22	6	4	12	4	16	2	12	7	3	11	7	4	10	9	3
07290910	36	13	22	1	7	25	4	18	12	6	13	20	3	15	16	5
07294400	13	2	6	5	0	5	8	1	5	7	1	5	7	4	6	3
07294400	5	0	0	4	0	0	5	1	0	4	0	0	5	2	3	0
07373550	4	0	0	4	0	0	4	1	0	3	0	0	4	3	1	0
07375235	26	7	7	6	15	5	0	15	3	2	7	3	10	12	7	1
07376665	27	8	7	11	6	14	7	12	11	4	10	9	8	10	7	10
07376665	12	0	3	6	0	7	5	5	6	1	4	7	1	4	4	4
07376760	24	0	2	18	0	18	6	20	2	2	7	11	6	10	10	4
MISSOURI																
05497700	12	6	2	4	10	2	0	11	0	1	10	1	1	4	6	2
05502700	18	3	6	9	4	9	5	9	6	3	12	3	3	6	7	5
05503000	18	0	7	11	0	13	5	11	5	2	7	7	4	5	7	6
06815550	8	1	1	6	0	6	2	8	0	0	6	1	1	2	3	3
06816000	25	16	8	1	0	14	5	14	6	5	6	12	7	10	10	5
06820000	28	9	7	10	17	7	4	19	8	0	16	7	5	9	8	11
06897700	23	3	3	16	3	15	5	9	8	6	7	8	8	5	11	7
06902500	29	1	3	16	6	18	5	25	4	0	23	3	3	9	14	6
06902800	11	8	3	0	8	3	0	8	2	1	6	3	2	3	5	3
06907200	13	3	5	5	2	11	0	9	4	0	10	1	2	7	5	1
06906300	15	5	4	6	2	9	4	10	3	2	7	4	4	5	6	4
06909700	16	5	6	5	0	4	12	5	7	4	2	4	10	6	2	8
06910250	11	4	5	2	2	6	3	9	0	2	8	1	2	5	3	3
06918700	14	2	8	4	2	9	3	9	4	1	6	3	5	2	2	10
06919200	17	1	7	4	0	6	6	1	7	4	1	8	3	4	2	6
06921740	31	3	11	17	0	11	20	19	8	4	16	11	4	6	9	16
06925300	14	12	2	0	11	1	2	8	5	1	7	5	2	8	3	3
06927100	13	3	6	4	6	6	1	12	1	0	9	3	1	6	5	2
06931500	43	19	17	7	13	25	5	33	5	5	22	13	8	11	17	15
06935800	34	8	16	10	0	25	9	24	7	3	17	7	10	9	11	14
07011200	9	2	2	5	3	5	1	6	2	1	4	2	3	2	4	3
07011500	27	4	8	15	0	4	23	16	7	4	8	14	5	7	10	10
07015500	19	0	1	18	0	6	13	13	6	0	9	7	3	9	4	6
07017500	24	7	7	11	0	24	2	19	4	3	11	11	4	12	7	7
07064300	18	9	2	7	0	14	4	13	3	2	8	8	2	3	11	4
07064500	27	3	12	12	6	15	6	16	9	2	10	13	4	6	12	9
07185500	23	8	7	8	3	15	5	15	2	6	3	11	9	8	12	3
TENNESSEE																
03312600	22	15	5	2	8	13	1	14	3	5	13	6	3	7	10	5
03313620	10	8	2	0	4	5	1	7	0	3	7	2	1	1	6	3
03410900	10	3	3	4	5	4	1	3	4	3	5	3	2	2	5	3
03420360	13	2	7	4	6	6	1	4	5	4	4	5	4	3	4	6
03420380	19	0	7	12	7	9	3	11	5	3	10	7	2	5	6	8
03420400	19	4	8	7	9	9	1	10	6	3	11	3	5	4	5	10
03430400	17	1	2	14	0	8	9	11	4	2	10	4	3	4	11	7
03431520	9	7	2	0	1	8	0	3	5	1	3	3	3	4	2	3
03431580	17	2	8	7	4	13	0	13	2	2	13	4	0	6	9	2
03431600	24	10	10	4	18	8	0	21	2	1	19	5	0	8	7	9
03431650	15	15	0	0	7	6	2	11	3	1	10	3	2	3	9	3
03435020	18	4	8	6	6	8	4	9	3	6	11	4	3	5	8	5
03435030	14	5	9	0	9	4	1	8	3	3	11	1	2	2	8	4
03435600	30	25	5	0	17	11	2	15	6	9	18	6	6	6	15	9

Table D.9 . continued

STA NO.	#FE	BASIN RESPONSE RO/RF LOW	MED	HIGH	Q/DA LOW	MED	HIGH	AVE PRECIP LOW	MED	HIGH	MODEL INPUT SIF 3HR LOW	MED	HIGH	AMI LOW	MED	HIGH
03461200	11	10	1	0	10	1	0	5	3	3	2	4	5	1	7	3
03469110	8	7	1	0	7	1	0	6	2	0	5	2	1	5	2	1
03466225	9	7	0	0	8	1	0	7	2	0	6	2	1	2	3	4
03519610	16	14	2	0	10	5	1	8	4	4	9	5	2	2	3	11
03519630	14	12	2	0	10	3	1	6	6	7	7	4	3	1	5	8
03519640	22	18	4	0	20	2	0	7	11	4	14	5	3	3	9	10
03519650	12	11	1	0	11	0	1	5	5	2	6	4	2	1	5	6
03525140	7	1	3	3	0	4	3	1	4	2	2	2	3	1	6	0
03535160	19	7	9	3	16	3	0	12	4	3	13	4	2	5	10	4
03525180	13	9	4	0	10	2	1	6	5	2	9	1	3	1	8	4
03538900	20	13	4	3	14	6	0	8	8	4	15	4	1	2	15	3
03539100	17	14	2	1	13	4	0	8	8	1	11	5	1	2	9	6
03597300	22	7	6	9	4	14	4	13	3	6	10	6	6	6	9	7
03597300	22	7	6	9	4	14	4	13	3	6	10	6	6	6	9	7
03597400	13	0	3	10	2	7	4	8	3	2	9	3	1	1	7	5
03597450	20	9	8	3	1	11	8	10	5	5	6	8	6	4	5	11
03597450	20	9	8	3	1	11	8	10	5	5	6	8	6	4	5	11
03597500	19	2	5	12	7	8	4	13	4	2	12	5	2	6	7	6
03597550	20	4	10	6	3	15	2	9	7	4	7	8	5	3	10	7
03597550	20	4	10	6	3	15	2	9	7	4	7	8	5	3	10	7
03604070	6	1	4	1	0	5	1	1	2	3	0	1	5	0	4	2
03604080	8	6	0	2	6	0	2	2	3	3	3	0	5	2	4	2
03604090	15	10	2	1	8	4	3	2	6	7	4	4	7	4	7	4
03604100	12	7	4	1	6	5	1	3	3	6	4	1	7	1	7	4
07028935	17	2	5	10	1	5	11	7	6	4	9	4	4	4	11	2

Table D.10 Predicted Parameter Values

Using Equations from 'LARGE' Sample for All Sites in Study

	Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
ALA	02342200	1.9540	0.0788	15.5800	5.2600	2.6700	198.6000
	02343700	1.6800	0.0570	16.2100	5.5000	4.1710	264.6001
	02362745	2.0740	0.0597	16.9800	4.9600	2.7230	192.3000
	02363055	2.1800	0.0543	15.1900	5.1200	2.0090	141.2000
	02365310	1.2870	0.0517	18.9900	5.1700	2.7400	142.1000
	02371200	2.0530	0.0562	15.1100	4.9200	3.6450	225.9000
	02372510	1.5840	0.0473	16.9200	6.3300	2.7180	163.8000
	02399200	2.5480	0.0451	9.9700	3.5700	2.6470	224.6000
	02400033	2.5590	0.0869	13.2500	5.2800	1.1580	104.2000
	02400690	2.4050	0.0504	13.9500	3.1800	2.3340	181.1000
	02407500	2.5000	0.0336	12.6000	3.0300	3.9820	257.2000
	02408340	1.5310	0.0528	13.0400	5.1100	4.2110	247.5000
	02410000	2.1620	0.0631	13.9300	5.0900	2.4840	158.3000
	02412220	2.5890	0.0571	12.0900	5.1600	1.1970	103.9000
	02413400	2.0040	0.0880	14.7600	5.6800	2.8690	203.3000
	02414200	1.9570	0.0570	12.6500	5.3400	2.2070	163.9000
	02417400	2.0270	0.0674	14.5100	5.0800	1.9290	114.9000
	02421300	2.0350	0.0605	15.4900	4.3600	4.0380	256.6001
	02427013	1.2480	0.0178	11.9600	2.9700	1.6210	120.7000
	02437800	1.7600	0.0948	16.7500	5.3500	2.6280	195.7000
	02437900	1.9180	0.1193	20.2300	5.9000	3.7750	245.6000
	02449400	1.2830	0.0260	12.1000	3.2500	2.4310	162.4000
	02450200	2.0830	0.0588	14.4700	3.8500	2.7910	214.7000
	02451550	1.7360	0.0824	13.9400	5.7200	1.4060	110.9000
	02451750	1.7830	0.0767	13.6300	5.6200	0.9930	89.6000
	02453500	1.5720	0.0448	11.8600	3.4400	2.7970	192.9000
	02462600	2.6190	0.0591	16.1700	3.7500	1.9260	155.8000
	02465205	2.1950	0.0559	14.0000	3.8300	1.7680	140.6000
	02471026	1.7780	0.0413	19.5000	6.7900	3.1680	181.7000
	02479583	1.6250	0.0380	17.9100	5.5000	5.6430	270.9000
	03574405	1.6970	0.0459	14.0000	3.5900	1.2830	111.2000
	03585380	2.0630	0.0463	14.1000	3.0100	2.6910	189.9000
GA	02189020	1.4620	0.0711	16.8600	5.4200	3.8800	260.2000
	02189030	1.6300	0.0627	17.6400	5.8200	1.1940	88.2000
	02191270	1.9230	0.1011	16.0100	4.9500	4.5460	263.3999
	02191280	2.0280	0.0614	15.3400	6.3200	0.7400	59.2000
	02191600	1.5710	0.0921	16.7400	5.4200	3.5360	229.3000
	02191750	1.4240	0.0920	17.1600	5.2500	8.4040	451.3000
	02192200	1.5330	0.1092	15.3500	5.3200	0.5120	41.6000
	02192400	1.7040	0.1122	16.6200	4.8800	4.2530	256.5000
	02192420	1.5660	0.1161	16.2900	4.9600	1.5540	107.4000
	02193600	1.9140	0.1175	15.8000	4.9600	1.7300	119.7000
	02201110	1.3600	0.0913	17.5600	4.0400	6.0520	311.2000
	02201160	1.3740	0.0909	17.3100	4.1200	5.5710	283.0000
	02201830	1.3350	0.0884	14.0000	6.4600	4.3300	246.6000
	02202510	1.1800	0.0739	16.7900	4.7600	4.3110	191.5000
	02202950	1.1210	0.0667	16.0500	4.7000	5.3890	237.0000
	02208200	1.9190	0.1012	15.7300	6.0200	1.4410	100.6000
	02211459	1.7030	0.0950	15.5900	5.1000	1.8420	135.9000
	02215280	1.5370	0.0685	13.2700	4.7700	3.7340	199.7000
	02216610	1.4670	0.0832	17.3100	5.4800	4.7100	214.6000
	02217250	2.6660	0.0910	16.8200	5.7200	0.9750	71.8000
	02217400	2.0070	0.1018	16.6500	4.9800	2.2310	151.0000
	02217660	2.3650	0.0921	17.0700	5.3400	2.1560	125.8000

Table D.10 , continued

'LARGE' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02218100	1.5840	0.0854	16.2700	4.5000	2.5280	154.1000
02223700	1.4940	0.0609	15.3200	4.6700	3.0630	182.8000
02224200	1.2360	0.0670	12.7300	4.8600	7.0000	367.8000
02225330	1.2570	0.0789	17.0700	4.7200	6.2910	335.5000
02315980	1.4350	0.0679	14.7900	4.3000	4.1340	179.1000
02316220	1.0150	0.0575	11.7400	5.3700	3.5830	182.4000
02316260	0.5330	0.0434	11.4100	5.9100	25.4620	648.3000
02317710	1.1830	0.0628	13.5900	5.2400	5.2710	195.7000
02317760	1.1220	0.0757	17.7000	4.4800	8.5600	395.7000
02317765	1.2410	0.0786	17.4300	4.8400	3.4550	175.3000
02317770	1.1770	0.0795	17.4700	4.6400	6.4560	322.6001
02317775	1.2820	0.0771	17.5700	4.7700	3.8770	181.4000
02317780	1.2740	0.0760	17.4700	4.7100	2.2080	117.3000
02317795	1.3390	0.0727	16.0400	4.6900	4.9460	262.5000
02317845	1.2840	0.0656	17.4900	4.5800	4.2170	206.5000
02317505	1.2030	0.0677	15.4600	4.7800	4.8680	244.3000
02317910	1.1840	0.0551	12.8400	4.9100	2.9040	169.9000
02318015	1.2290	0.0585	13.5700	5.6900	2.9450	155.8000
02318020	1.2400	0.0467	12.3700	6.1800	1.9530	98.2000
02327350	1.3780	0.0649	17.1600	5.3600	4.5900	212.0000
02327400	1.1440	0.0659	18.3000	4.9500	7.1810	301.3959
02346193	1.8420	0.0899	17.0800	5.2700	3.3450	217.2000
02346210	2.1000	0.0966	16.8200	5.2600	3.5690	236.5000
02346217	2.5660	0.0946	16.5500	5.2200	2.2890	156.4000
02350520	1.3730	0.0734	15.4800	4.2500	5.0650	227.4000
02381100	1.6990	0.0628	11.7700	5.5200	1.2390	115.0000
02381600	2.0710	0.0753	12.5500	5.5100	2.0710	177.6000
02381900	1.6740	0.0644	12.3700	5.2200	1.6160	142.0000
02382000	1.9530	0.0334	11.8700	4.3100	1.3330	122.1000
02382900	3.0110	0.0606	11.5700	4.4500	2.9410	232.2000
02383000	2.7400	0.0564	12.5400	3.7400	2.2930	167.7000
02387300	1.9740	0.0408	12.3900	5.2000	0.7160	56.1000
02387560	2.9860	0.0498	12.2800	3.4600	2.1430	153.0000
02387700	2.0300	0.0623	10.4900	5.5700	2.3030	190.8000
02387800	3.4370	0.0534	15.3300	3.6700	3.0050	190.2000
02388200	3.4160	0.0566	13.0800	3.8700	2.2720	169.2000
02388400	2.9780	0.0607	14.5400	4.1900	1.8650	140.6000
02397750	3.0250	0.0528	20.7600	2.5400	3.6100	223.5000
03566660	2.3610	0.0642	16.0400	3.7800	3.0740	202.1000
03566687	2.6720	0.0547	16.8600	3.8600	2.5490	172.8000
ILL 03338100	1.8450	0.0875	16.8500	3.1300	1.3210	100.2000
03344250	1.4720	0.0373	11.0100	2.7300	0.6410	48.0000
03380300	1.8820	0.0268	9.5300	2.4000	0.5880	44.7000
03380450	2.5580	0.0492	11.1600	3.3200	0.7710	68.1000
03381600	3.1520	0.0848	15.0600	3.7000	0.5470	50.1000
03382025	2.6550	0.0520	12.6300	3.5400	0.8280	71.9000
05418800	3.2610	0.0925	13.2800	3.1500	0.5500	55.1000
05437600	2.6930	0.1094	16.5200	3.0200	0.8470	79.1000
05438850	2.2090	0.0979	16.2800	2.8500	0.7800	71.1000
05439550	2.7390	0.1085	16.0200	3.0400	0.8470	78.2000
05448050	2.1510	0.0846	15.0900	3.9700	0.2880	32.3000
05469750	1.8190	0.0693	15.6900	3.3400	0.8110	64.0000
05495200	2.1580	0.0669	14.0800	3.5100	1.5480	115.6000

Table D.10 , continued

'LARGE' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
05502120	2.5120	0.0605	13.7100	3.0700	1.2530	86.4000
05527050	1.3710	0.0434	10.2000	2.1000	1.8420	117.8000
05536265	0.5840	0.0879	13.0000	2.2000	5.1110	218.9000
05541750	0.5800	0.0620	13.2600	2.5800	6.1730	258.5000
05551800	2.5060	0.1015	16.2400	3.1600	0.6920	60.5000
05554600	1.5580	0.0402	9.9900	2.2800	0.2730	30.0000
05555400	1.7080	0.0598	11.9800	2.9200	0.3450	33.5000
05557100	2.7350	0.1042	15.7800	4.1700	0.2330	31.3000
05558050	2.5250	0.0613	10.8900	3.0700	0.0860	12.9000
05558075	3.2950	0.0968	15.1400	3.1500	0.1460	21.9000
05566000	1.6660	0.0841	15.7400	2.9000	2.8330	166.8000
05572100	1.6120	0.0674	14.1700	3.1800	0.4950	35.8000
05577520	1.2360	0.0501	13.9400	2.9800	2.1150	113.4000
05577700	1.8680	0.0618	13.7700	3.3600	1.0450	81.6000
05586500	1.7910	0.0593	14.0200	2.9600	2.7160	155.9000
05587850	2.5080	0.0558	12.4900	3.2400	0.8280	71.0000
05591500	1.3550	0.0667	15.0500	2.9300	4.5180	221.5000
05594200	1.5790	0.0386	11.8600	2.9700	2.2570	144.5000
05595550	2.6230	0.0708	15.0900	3.5300	1.1440	88.0000
05596100	1.5610	0.0349	10.8100	2.7000	1.6270	111.0000
05599640	4.0500	0.0714	14.1400	3.9700	0.6390	63.1000
MISS 02429580	1.8580	0.0674	12.3000	4.3400	1.6740	124.2000
02435300	1.8320	0.0299	9.8300	3.9400	0.5450	43.5000
02435400	1.7500	0.0660	13.7700	4.4500	1.2760	88.9000
02437550	2.2700	0.0602	15.6400	4.0200	1.2750	94.1000
02440020	1.8060	0.0178	10.4500	1.9100	0.8750	61.7000
02441220	1.8760	0.0180	10.3200	2.4200	1.5060	91.1000
02447340	1.8620	0.0285	12.0700	3.8700	1.7810	114.7000
02475220	2.6880	0.0472	13.1700	5.1600	0.7390	56.7000
02477090	1.2300	0.0162	10.9900	3.3900	1.0080	72.2000
02477090	1.2300	0.0162	10.9900	3.3900	1.0080	72.2000
02478600	1.6650	0.0371	13.0400	4.3900	1.4050	96.3000
02479165	2.1330	0.0432	15.4300	5.2800	1.1740	65.7000
02481505	1.6990	0.0393	15.0500	6.6500	3.3840	175.3000
02485780	2.0600	0.0274	12.1300	3.9000	1.1050	72.7000
02485900	1.9680	0.0293	11.6100	4.4400	1.5570	116.8000
02485900	1.9680	0.0293	11.6100	4.4400	1.5570	116.8000
02487670	2.3550	0.0585	16.2700	4.2400	1.3460	94.6000
02487710	2.0450	0.0593	17.5700	4.1100	1.5970	111.8000
02488550	2.3580	0.0567	16.4900	4.1600	0.5820	68.5000
02488680	1.7960	0.0384	12.5900	6.2300	0.9110	70.5000
02489030	2.1500	0.0482	15.5700	4.4400	1.3300	93.2000
02489160	1.7520	0.0430	14.4300	4.5300	1.3320	92.0000
07029252	2.0480	0.0677	13.9800	5.1000	1.5380	102.8000
07267200	1.9380	0.0337	10.3500	3.9800	0.9370	64.8000
07277550	1.9950	0.0453	12.9000	4.3500	0.7390	50.5000
07282300	1.8290	0.0343	12.6400	3.6300	2.3660	113.8000
07285700	2.7330	0.0463	14.0500	3.9500	1.9950	129.7000
07287140	0.9260	0.0228	11.8500	4.0200	1.1370	72.9000
07287520	2.4960	0.0505	16.0800	3.9800	2.2240	138.6000
07287520	2.4960	0.0505	16.0800	3.9800	2.2240	138.6000
07288568	1.1350	0.0109	10.3300	1.8400	0.4780	40.2000
07289640	1.8880	0.0288	12.1500	4.1900	0.6640	51.6000
07289640	1.8880	0.0288	12.1500	4.1900	0.6640	51.6000

Table D.10 , continued

'LARGE' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
07290220	2.0440	0.0399	14.6900	5.8000	0.7020	55.5000
07290525	2.0640	0.0288	11.7700	4.3200	1.7600	122.8000
07290510	2.6170	0.0381	16.2600	4.0000	1.8140	133.5000
07294400	3.9440	0.0359	15.2400	5.1800	0.8030	71.5000
07294400	3.9440	0.0359	15.2400	5.1800	0.8030	71.5000
07373550	2.7680	0.0337	16.6900	4.4800	0.8550	59.9000
07375235	1.7480	0.0332	13.2700	4.6000	2.5190	153.2000
07376665	2.1060	0.0319	13.9300	4.4200	1.2360	83.6000
07376665	2.1060	0.0319	13.9300	4.4200	1.2360	83.6000
07376760	1.6140	0.0244	12.3600	4.9400	2.8190	142.4000
05497700	2.1290	0.0487	11.9100	2.5200	0.7670	78.5000
MD 05502700	1.6830	0.0387	10.5800	2.8400	0.7970	69.2000
05503000	1.3020	0.0293	10.1900	2.3300	1.4550	109.5000
06815550	2.9520	0.0753	16.1700	3.0900	0.4040	43.1000
06816000	2.9010	0.0728	16.0500	2.5900	1.6130	125.5000
06820000	2.3150	0.0730	16.2800	2.5400	1.4160	126.3000
06897700	2.4580	0.0524	12.3600	2.7100	0.9470	79.4000
06902500	2.7420	0.0667	15.0900	2.9200	0.9120	92.7000
06902800	3.0410	0.0739	17.3500	2.9300	0.4260	50.3000
06907200	1.2910	0.0340	11.1500	3.1000	0.5660	57.5000
06908300	3.0950	0.0656	15.0500	3.2000	0.6450	63.7000
06909700	1.8410	0.0583	13.6600	4.1900	0.5140	50.3000
06910250	1.8040	0.0442	9.9500	2.9200	0.6800	57.3000
06918700	2.6530	0.0376	11.3900	2.8700	1.3090	102.2000
06919200	3.0860	0.0804	16.0400	3.3800	0.1680	21.0000
06921740	2.4650	0.0520	11.9000	3.5100	0.6530	67.4000
06925300	2.2250	0.0505	13.4700	3.3700	0.9680	79.0000
06927100	1.7930	0.0389	10.9600	2.7900	0.3810	40.4000
06931500	1.7550	0.0356	9.0400	3.0800	1.7530	139.2000
06935800	2.5710	0.0429	11.6800	2.4700	0.6100	57.9000
07011200	2.3040	0.0561	13.9900	3.7400	1.5510	100.6000
07011500	1.8750	0.0736	14.4000	5.1800	0.4080	42.7000
07015500	1.6990	0.0488	12.2200	3.3200	1.3950	79.9000
07017500	2.3320	0.0453	12.0600	2.8100	1.5540	131.1000
07064200	2.2370	0.0657	14.9600	4.0700	2.2360	145.7000
07064500	2.4980	0.0556	14.9300	3.4900	3.3130	210.7000
07185500	2.2800	0.0514	15.7700	3.3500	1.6170	128.0000
TENN 03313600	2.6740	0.0827	19.2600	3.9100	1.0440	85.0000
03313620	2.6020	0.0835	19.0900	3.7900	1.8170	137.9000
03418900	1.6280	0.0800	14.0600	4.8400	0.9700	84.7000
03420360	2.1230	0.0508	13.9200	3.3000	2.5340	155.1000
03420380	1.8180	0.0466	13.0500	3.6900	2.2290	134.2000
03420400	2.2300	0.0536	13.9500	3.4800	3.3820	217.2000
03430400	2.1880	0.0401	10.5300	2.5900	3.5440	232.3000
03431520	3.2320	0.0899	16.2800	3.8400	1.5930	132.3000
03431580	2.5510	0.0615	14.3200	2.9900	2.0010	160.1000
03431600	2.4540	0.0827	16.9200	3.4900	5.4360	407.6001
03431650	3.4080	0.0583	13.2000	3.0500	0.8520	83.0000
03435020	2.5470	0.0907	18.6300	3.5000	1.9080	154.0000
03435030	2.4400	0.0904	18.7400	3.4500	2.2010	183.8000
03435600	2.5270	0.0733	14.7900	3.3500	1.4470	115.1000
03461200	2.3960	0.0707	9.9500	3.5300	1.1550	110.6000
03469110	2.5120	0.0580	7.0000	3.0000	0.5630	66.5000
03486225	3.6690	0.1452	14.8500	2.9200	1.0480	97.5000

Table D.10 , continued

'LARGE' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
03519610	3.5700	0.0663	16.5100	2.6300	1.4390	110.6000
03519630	3.8620	0.0615	15.7900	2.4100	1.1480	85.3000
03519640	2.9050	0.0606	15.3000	2.3100	1.8510	163.6000
03519650	3.2870	0.0614	15.4300	2.2900	1.8220	138.9000
03535140	2.3770	0.0778	11.7500	3.9900	0.9780	77.1000
03535160	2.0720	0.0745	13.0200	3.4800	3.1880	219.3000
03535180	2.5610	0.0781	14.8300	3.5000	1.5340	122.3000
03538900	1.7510	0.0852	17.9000	4.2300	2.7170	180.0000
03539100	1.8040	0.0854	16.6800	4.4300	1.8620	127.7000
03597300	2.4200	0.0566	11.5100	3.0500	2.1380	158.5000
03597300	2.4200	0.0566	11.5100	3.0500	2.1380	158.5000
03597400	2.3760	0.0564	11.4600	2.9900	2.7780	205.7000
03597450	3.0260	0.0659	12.4300	3.2100	0.6260	59.6000
03597450	3.0260	0.0659	12.4300	3.2100	0.6260	55.6000
03597500	2.1770	0.0543	10.9300	2.9700	2.7600	218.1000
03597550	1.8450	0.0462	10.7700	3.2200	1.4320	116.6000
03597550	1.8450	0.0462	10.7700	3.2200	1.4320	116.6000
03604070	3.3500	0.0656	14.9100	5.4800	0.8050	68.3000
03604080	3.1140	0.0689	15.5500	5.3800	1.3250	107.7000
03604090	3.1120	0.0683	15.2700	5.0800	2.0240	162.0000
03604100	2.9330	0.0676	15.1500	5.0800	2.8720	220.9000
07028935	2.7600	0.0639	17.2300	3.0400	0.7080	67.6000

Table D.10 , continued

Using Equations from 'SMALL' Sample for All Sites in Study

	Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
AL	02342200	1.3560	0.0707	12.9700	4.0100	1.1900	171.8000
	02343700	1.1210	0.0578	14.0900	3.0100	2.1180	268.6001
	02362745	1.0820	0.0519	14.9900	3.3500	1.2760	160.6000
	02363055	1.2170	0.0518	13.0900	3.1700	1.0630	105.7000
	02365310	1.4860	0.0627	20.5700	3.1200	2.7760	151.5000
	02371200	0.9800	0.0519	11.7100	2.8100	1.8020	204.0000
	02372510	1.4880	0.0538	14.8300	3.1400	1.7440	141.1000
	02399800	1.9240	0.0375	5.7200	2.9100	0.8860	176.1000
	02400033	3.0510	0.0687	4.9400	4.9400	0.6150	114.5000
	02400690	1.7930	0.0381	13.0200	2.5600	1.1100	153.4000
	02407900	1.4120	0.0316	14.7000	1.7100	1.8580	234.3000
	02408340	2.9610	0.0495	11.0300	3.5400	2.2310	225.7000
	02410000	1.6150	0.0529	10.9200	3.1900	1.4890	149.2000
	02412320	4.0970	0.0523	8.2400	4.4300	0.6170	79.6000
	02413400	1.1670	0.0745	10.1500	4.9300	1.4490	173.1000
	02414800	2.5190	0.0520	9.8600	4.1500	1.0550	149.9000
	02417400	1.5000	0.0590	12.0300	3.2400	1.4860	86.6000
	02421300	0.7350	0.0476	11.8600	2.5100	2.1590	227.7000
	02427013	2.7730	0.0140	19.9200	1.5100	1.2490	138.0000
	02437800	2.1160	0.0813	8.0700	4.7300	1.0640	180.5000
	02437900	1.5040	0.1118	7.0000	4.7700	1.7260	217.7000
	02449400	2.1740	0.0215	18.3500	1.8400	1.6280	251.9000
	02450200	1.4310	0.0542	13.0300	2.7600	1.0690	180.3000
	02451550	1.2710	0.0771	10.5300	5.4200	0.7930	80.9000
	02451750	1.5740	0.0735	11.0300	5.2400	0.5570	81.0000
	02453900	0.8000	0.0371	14.2300	2.8200	1.3710	159.3000
	02462600	1.2790	0.0485	13.6100	2.5800	0.8530	135.7000
	02465205	0.9320	0.0439	12.1500	2.7900	0.8060	113.9000
	02471026	3.4950	0.0466	17.6700	4.1200	2.1190	159.7000
	02479583	1.1940	0.0418	17.9800	2.5600	4.2840	277.5000
	03574405	2.0220	0.0426	18.6800	2.9900	0.7100	117.7000
	03585380	1.1600	0.0466	19.2100	2.3900	1.7670	192.4000
GA	02189020	2.4290	0.0627	14.5000	5.2500	1.8920	219.8000
	02189030	7.2770	0.0572	17.3800	5.9700	0.8460	57.6000
	02191270	0.9250	0.0816	12.1200	4.1100	2.5630	258.8000
	02191280	1.7500	0.0781	12.5700	6.3800	0.6380	58.1000
	02191600	0.8990	0.0842	14.0200	4.6200	2.0250	219.8000
	02191750	0.9620	0.0898	15.5500	4.1700	5.2250	474.6001
	02192300	1.5850	0.1002	12.6900	5.0700	0.5090	31.4000
	02192400	1.0110	0.0989	13.9700	4.3600	2.5250	228.5000
	02192420	1.3180	0.1015	12.9500	4.4200	1.2390	91.1000
	02193600	1.3690	0.0936	14.7400	4.6100	1.3560	110.2000
	02201110	0.9440	0.0896	18.4300	2.7500	4.1350	320.3000
	02201160	1.0950	0.0909	18.1900	2.8200	3.6650	296.3999
	02201830	1.5410	0.1065	10.6100	4.9400	2.7350	223.4000
	02202910	1.3820	0.0900	18.0400	3.2400	4.5460	174.7000
	02202950	0.9930	0.0756	18.0600	3.1200	5.4230	198.6000
	02208200	1.6430	0.0944	11.8100	5.6000	1.1410	92.2000
	02211459	0.9820	0.0863	12.5400	4.7900	1.0900	115.9000
	02215280	1.1080	0.0733	13.9900	3.4000	2.6910	160.5000
	02216610	1.5650	0.0981	13.6000	3.5900	3.7280	190.8000
	02217250	5.5080	0.0777	15.3900	6.2700	0.8810	71.3000
	02217400	1.3040	0.0859	13.1300	4.9000	1.4820	148.8000
	02217660	3.3200	0.0787	15.3300	5.4000	1.9570	116.5000

Table D.10 , continued

'SMALL' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02218100	1.0010	0.0807	16.2600	3.9700	2.0380	151.0000
02223700	1.1830	0.0842	15.8400	3.6600	1.9560	149.8000
02224200	0.8810	0.0702	13.7200	3.4400	3.6070	356.0000
02225330	1.0590	0.0861	17.3100	3.2300	3.6590	325.2000
02315980	1.1150	0.0761	16.2800	2.8800	4.4220	168.9000
02316220	0.7440	0.0717	11.6900	3.5900	2.8290	133.2000
02316260	0.7710	0.0766	12.5300	4.2600	28.1370	541.3999
02317710	1.1210	0.0820	13.9500	3.6200	6.2950	162.1000
02317760	1.0410	0.0854	19.0600	2.8500	5.9780	379.1001
02317765	1.3050	0.0893	17.7400	3.1300	3.0720	128.6000
02317770	1.0840	0.0894	17.0000	2.9400	4.3420	285.0000
02317775	1.3600	0.0886	18.1100	3.1300	3.5690	148.9000
02317780	1.4140	0.0879	18.1600	3.0200	2.5760	112.8000
02317795	1.0800	0.0826	16.4900	3.2100	3.4110	272.5000
02317845	1.3760	0.0723	20.1700	2.9600	3.9130	192.7000
02317905	1.0300	0.0798	16.2400	3.2100	4.0700	250.7000
02317910	0.9570	0.0642	14.2400	3.2900	2.2680	140.5000
02318015	1.2300	0.0691	13.1500	3.7800	2.4620	128.7000
02318020	1.9820	0.0572	14.2200	4.2900	2.1360	75.1000
02327350	1.3630	0.0729	16.0800	3.3700	4.1850	183.3000
02327400	1.2120	0.0785	19.6400	3.1400	6.6140	298.1001
02346193	1.2580	0.0801	14.5300	4.1400	1.7080	163.8000
02346210	1.6190	0.0791	13.7300	4.2000	1.7380	208.0000
02346217	2.7040	0.0747	12.8100	4.1700	1.3540	138.5000
02350520	1.0980	0.0807	15.3400	2.6200	4.2060	203.7000
02381100	1.4920	0.0616	8.4000	5.4600	0.5900	98.1000
02381600	1.8310	0.0720	5.9100	5.4000	0.8650	181.2000
02381900	1.5070	0.0631	10.4700	5.2400	0.7640	118.1000
02382800	3.7550	0.0442	10.4500	3.3600	0.5640	102.9000
02382900	2.6340	0.0484	6.3300	3.8700	1.1630	212.5000
02383000	2.7650	0.0494	12.2300	3.5600	1.0750	158.7000
02387300	3.9680	0.0526	15.7300	4.1800	0.6130	40.7000
02387560	2.5850	0.0379	12.6100	2.9000	1.1410	135.9000
02387700	2.2040	0.0583	2.9300	4.6800	0.9350	162.2000
02387800	4.3620	0.0532	13.1800	2.5500	1.7690	172.1000
02388200	3.7860	0.0490	10.1200	3.0400	1.0730	169.7000
02388400	3.7070	0.0516	13.4700	3.3500	1.0900	131.3000
02397750	2.2660	0.0377	28.9500	1.8800	2.1490	229.6000
03566660	1.4800	0.0570	15.6200	2.8600	1.5370	158.7000
03566687	2.9280	0.0585	18.6400	2.7700	1.4290	154.6000
ILL 03338100	1.6780	0.0748	19.4400	2.7900	1.6000	136.2000
03344250	0.9220	0.0408	19.0100	2.3300	0.9590	41.8000
03380300	0.5040	0.0261	17.5200	1.7800	0.5910	29.3000
03380450	1.8590	0.0467	14.7300	2.7100	0.6020	58.6000
03381600	2.2340	0.0662	14.7300	3.5200	0.3720	30.4000
03382025	1.9740	0.0509	15.2100	2.7100	0.5440	54.5000
05418800	2.5890	0.0850	11.8300	2.3400	0.4360	61.2000
05437600	2.1190	0.1001	18.0500	2.9600	0.7040	101.1000
05438850	1.6700	0.0833	18.5800	2.3100	0.8580	98.9000
05439550	1.8880	0.0994	17.4200	2.9900	0.6340	86.4000
05448050	2.3960	0.0806	17.3200	3.0000	0.3480	38.5000
05469750	1.6770	0.0659	19.0100	2.4500	1.3630	68.8000
05495200	1.7650	0.0627	18.2600	2.5500	1.3750	137.8000

Table D.10 , continued

'SMALL' Equations

	Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
	05502120	1.8710	0.0561	16.8000	1.9300	1.2190	92.7000
	05527050	1.5080	0.0341	18.5800	1.8900	1.7710	100.4000
	05536265	0.5840	0.0797	18.5900	1.4400	7.7160	316.8999
	05541750	1.5240	0.0611	19.8900	2.0200	11.5550	428.7000
	05551800	2.3170	0.0958	17.5500	2.7600	0.6570	63.4000
	05554600	1.0630	0.0352	17.8100	1.8200	0.3550	31.6000
	05555400	1.6120	0.0576	18.1900	2.2000	0.5250	33.9000
	05557100	2.9690	0.1071	14.7000	3.4500	0.2550	35.5000
	05558050	2.1800	0.0607	15.9800	2.6300	0.1150	12.8000
	05558075	2.2520	0.0830	15.3700	2.5800	0.1470	26.2000
	05566000	1.5130	0.0707	19.1200	2.1400	3.1710	283.1001
	05572100	1.8410	0.0629	19.1300	2.6400	0.9390	40.3000
	05577520	1.7780	0.0504	19.2300	1.8400	3.9400	175.7000
	05577700	2.0980	0.0552	18.3300	2.4200	1.1420	127.4000
	05586500	1.3150	0.0591	18.0000	1.8000	3.1350	185.5000
	05587850	1.5260	0.0509	15.9200	2.4400	0.6160	55.1000
	05591500	1.4820	0.0581	19.5400	2.1000	5.5640	344.8000
	05594200	1.1260	0.0442	18.6700	1.8700	2.5470	176.1000
	05595550	1.9890	0.0561	15.7900	2.4500	0.9370	72.0000
	05596100	1.1030	0.0353	17.6600	1.8300	1.5300	112.0000
	05599640	2.3260	0.0584	6.5800	3.3300	0.3380	39.5000
MISS	02429580	0.8100	0.0562	9.7400	3.6400	0.8560	82.7000
	02435300	2.2720	0.0254	14.7300	3.2300	0.4840	28.6000
	02435400	1.1070	0.0589	13.6700	3.7300	0.8540	56.2000
	02437550	1.5300	0.0473	16.7000	3.3400	0.9350	68.5000
	02440020	1.0560	0.0116	19.3600	1.1200	1.2750	83.2000
	02441220	1.4350	0.0128	18.7000	1.4500	1.6960	80.3000
	02447240	1.3560	0.0322	17.2200	2.1900	1.3010	69.5000
	02475220	1.7890	0.0403	12.0900	3.8000	0.5400	35.5000
	02477090	4.5160	0.0142	19.3300	2.2800	0.8040	54.6000
	02477090	4.5160	0.0142	19.3300	2.2800	0.8040	54.6000
	02478600	0.8910	0.0339	15.0900	2.8600	0.8920	63.7000
	02479165	1.0030	0.0382	14.8600	3.2000	1.2910	46.9000
	02481505	1.7010	0.0410	14.1300	3.7200	2.4990	145.7000
	02485780	1.8210	0.0323	17.3400	1.9700	1.0400	56.3000
	02485900	1.6790	0.0320	15.1900	2.7000	0.8050	79.8000
	02485900	1.6790	0.0320	15.1900	2.7000	0.8050	79.8000
	02487670	1.0140	0.0472	15.2700	2.7000	0.8670	73.7000
	02487710	0.9550	0.0505	17.7800	2.6800	1.0380	71.5000
	02488550	1.0150	0.0458	15.3600	2.5900	0.7040	45.8000
	02488680	2.0620	0.0408	13.0800	4.4400	0.6350	35.5000
	02489030	1.0160	0.0413	15.6700	2.8600	0.8750	71.9000
	02489160	0.9420	0.0396	16.2300	2.8500	1.0690	92.1000
	07029252	2.4010	0.0579	11.1500	4.5400	0.5890	70.1000
	07267200	1.6090	0.0289	14.2400	3.2300	0.7890	41.4000
	07277550	2.5520	0.0430	16.3300	3.0900	0.9020	52.7000
	07282300	1.7810	0.0384	17.7600	2.2300	2.3720	83.2000
	07285700	1.8380	0.0414	15.4500	2.6300	1.2310	105.7000
	07287140	1.5480	0.0264	20.0700	2.7900	1.7850	85.2000
	07287520	1.7610	0.0384	15.6900	2.4800	1.5490	102.1000
	07287520	1.7610	0.0384	15.6900	2.4800	1.5490	102.1000
	07288568	0.4760	0.0119	20.7200	1.1300	0.5900	40.8000
	07289640	1.7840	0.0346	17.4600	2.4300	0.7890	51.5000
	07289640	1.7840	0.0346	17.4600	2.4300	0.7890	51.5000

Table D.10 , continued

'SMALL' Equations

State	Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
	07290220	3.5050	0.0406	16.2000	4.0900	0.5280	36.5000
	07290525	1.6700	0.0327	15.2600	2.4300	1.0520	81.1000
	07290510	1.6050	0.0341	15.9800	2.1200	1.1410	103.2000
	07294400	3.0610	0.0335	12.5800	3.1000	0.5220	42.1000
	07294400	3.0610	0.0335	12.5800	3.1000	0.5220	42.1000
	07373550	1.9930	0.0352	18.9000	2.4900	0.9110	48.2000
	07375235	1.0220	0.0317	16.3200	2.7500	1.8400	146.6000
	07376665	1.3140	0.0306	17.6000	2.8500	1.2300	67.7000
	07376665	1.3140	0.0306	17.6000	2.8500	1.2300	67.7000
	07376760	2.0630	0.0317	17.6300	2.8500	2.6050	115.3000
MO	05497700	1.3150	0.0471	17.6100	1.5800	0.5200	97.1000
	05502700	1.6360	0.0401	17.1500	1.9100	0.6270	67.8000
	05503000	0.9040	0.0344	18.1100	1.3800	1.1450	128.9000
	06815550	1.8810	0.0692	17.9600	1.9700	0.4720	57.8000
	06816000	1.6670	0.0666	17.9200	1.3200	1.2790	179.7000
	06820000	1.2610	0.0694	18.8000	1.3800	1.1280	172.5000
	06897700	2.1710	0.0465	17.3600	1.6500	0.8560	107.9000
	06907500	2.2880	0.0615	17.3000	1.7500	0.5630	92.5000
	06902800	3.2950	0.0691	19.1400	1.7700	0.3380	58.6000
	06907200	1.6940	0.0464	18.4100	1.7800	0.5530	87.0000
	06908300	1.9390	0.0598	15.9200	2.1400	0.4690	64.3000
	06909700	3.0720	0.0763	16.7700	2.5700	0.5130	52.5000
	06910250	1.2930	0.0346	15.4000	2.0000	0.6170	64.6000
	06918700	2.0780	0.0350	15.2900	1.6200	0.7550	77.0000
	06919200	2.4170	0.0578	17.2900	2.2100	0.2170	25.7000
	06921740	2.1280	0.0442	14.9500	2.3400	0.4220	66.8000
	06925300	3.9990	0.0481	17.2800	2.1800	0.7330	82.7000
	06927100	1.3180	0.0414	17.0700	1.6000	0.4590	54.3000
	06931500	1.1690	0.0274	11.6900	2.0200	0.9300	156.3000
	06935800	1.5880	0.0412	17.0400	1.3300	0.4770	62.0000
	07011200	3.5770	0.0635	16.3400	2.6100	1.2570	88.2000
	07011500	3.4750	0.0703	14.4400	3.6300	0.3480	45.1000
	07015500	1.5440	0.0410	18.0500	2.3100	1.5720	60.4000
	07017500	1.5380	0.0453	17.4900	1.8700	0.9730	128.3000
	07064300	3.8050	0.0677	15.2400	3.1000	1.5350	126.2000
	07064500	3.6380	0.0602	17.5900	2.0800	1.9390	245.0000
	07185500	1.5940	0.0546	18.5300	1.8200	1.0940	151.3000
TENN	03313600	4.2120	0.0897	21.1700	4.0100	0.7530	77.3000
	03313620	3.6130	0.0887	20.2800	3.7700	1.0910	130.2000
	03418500	1.8020	0.0816	13.0600	4.8300	0.5280	73.2000
	03420360	1.4340	0.0499	18.5000	2.9200	1.8760	143.4000
	03420380	1.9420	0.0465	18.7500	3.6200	1.7610	116.9000
	03420400	1.9120	0.0482	17.9400	3.2800	2.0470	242.4000
	03430400	1.3220	0.0287	14.4800	1.9700	1.6570	242.8000
	03431520	5.1510	0.0877	7.1300	3.5700	0.7250	118.0000
	03431580	3.1120	0.0582	13.7900	2.2500	1.0290	212.2000
	03431600	2.8440	0.0621	13.1900	2.9700	1.9850	398.3999
	03431650	3.6630	0.0529	11.9500	2.4700	0.5000	91.7000
	03435020	2.9110	0.0947	19.9100	3.2800	0.9930	135.4000
	03435030	2.5130	0.0939	18.7600	3.2000	1.1030	225.3000
	03435600	1.7830	0.0685	16.4200	3.3800	1.0700	132.3000
	03461200	1.5530	0.0528	1.2100	3.8100	0.5320	152.3000
	03469110	1.0940	0.0441	15.9000	3.0000	0.2670	66.3000
	03486225	3.0460	0.1096	10.9100	4.3700	0.5580	166.2000

Table D.10 , continued

'SMALL' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
03519610	2.8580	0.0397	17.0700	2.6200	0.9490	108.6000
03519630	2.8840	0.0364	17.9000	2.2800	0.7860	88.7000
03519640	1.4960	0.0358	16.5600	2.0700	1.0700	210.0000
03519650	1.8530	0.0359	16.3700	2.0900	1.0160	112.9000
03535140	2.3550	0.0723	7.2500	3.7500	0.6290	59.5000
03535160	1.7970	0.0651	11.2200	3.1700	1.4400	193.5000
03535180	2.6720	0.0716	13.8600	3.4700	0.8900	100.1000
03538900	1.4360	0.0632	18.5300	4.0000	1.4890	147.7000
03539100	1.4700	0.0618	18.4300	4.4200	1.1270	91.3000
03597300	1.6360	0.0419	9.8600	2.9100	1.2100	153.3000
03597300	1.6360	0.0419	9.8600	2.9100	1.2100	153.3000
03597400	1.3090	0.0415	9.8000	2.8100	1.3180	193.4000
03597450	2.2630	0.0496	9.0600	3.1700	0.4200	47.9000
03597450	2.2630	0.0496	9.0600	3.1700	0.4200	47.9000
03597500	1.1660	0.0392	8.8800	2.7500	1.2010	217.5000
03597550	1.5300	0.0365	12.6000	3.0900	0.8900	87.7000
03597550	1.5300	0.0365	12.6000	3.0900	0.8900	87.7000
03604070	6.6370	0.0707	11.4700	5.0700	0.4960	54.8000
03604080	5.6600	0.0729	10.0200	4.6000	0.7030	82.9000
03604090	4.5100	0.0696	9.1900	4.4700	0.8550	156.9000
03604100	4.0560	0.0692	9.0400	4.4500	1.1420	207.2000
07028935	1.9210	0.0609	21.5200	2.8000	0.5700	72.9000

Table D.10 , continued

Using Equations from 'SOUTH' Sample for Sites in Study in 'SOUTH' Region

	Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
ALA	02342200	2.3860	0.0936	17.0700	5.2800	4.2920	256.3000
	02343700	2.7270	0.0735	16.2300	4.5800	6.4250	369.8000
	02362745	3.7090	0.0724	17.1700	4.6700	5.3930	220.2000
	02363055	3.9310	0.0747	14.6900	4.3900	2.9750	155.6000
	02365310	1.7850	0.0664	22.2900	4.0100	3.0430	174.2000
	02371200	3.3900	0.0750	14.4100	4.4400	5.5640	318.3000
	02372510	3.2300	0.0733	18.9400	4.2800	3.5000	175.6000
	02399800	1.9480	0.0435	9.2000	4.5400	4.5160	336.0000
	02400033	1.6620	0.0944	12.4700	6.0600	1.4030	135.3000
	02400690	1.6270	0.0422	13.9600	3.7200	3.1660	259.3999
	02407900	2.2140	0.0326	11.6100	3.1100	5.3610	370.8999
	02408340	1.3110	0.0614	13.4500	4.4500	5.3190	344.8999
	02410000	2.3810	0.0752	12.4600	4.8300	2.6120	208.4000
	02412320	1.6740	0.0656	11.5400	5.3100	1.4150	107.8000
	02413400	2.3010	0.0983	13.6700	6.2100	3.7300	262.9000
	02414800	1.3720	0.0648	12.8000	5.0700	2.9190	215.8000
	02417400	1.9660	0.0773	13.1900	4.6100	1.4220	133.0000
	02421300	3.1270	0.0674	14.5100	4.4400	4.4570	375.8999
	02427013	1.2310	0.0121	10.0300	4.1800	2.1110	173.5000
	02437800	1.0360	0.1062	19.9300	5.1200	4.1620	307.6001
	02437900	1.2730	0.1549	25.2300	4.9000	4.7040	374.3000
	02449400	1.2140	0.0203	10.5600	4.3100	3.6350	351.2000
	02450200	1.6650	0.0626	15.7300	3.3500	4.7520	330.1001
	02451550	1.7650	0.0934	13.8800	5.3700	1.9230	124.9000
	02451750	1.7350	0.0881	13.4400	5.0900	1.4160	100.4000
	02453500	2.6160	0.0397	9.4200	4.6500	4.2560	223.6000
	02462600	2.6200	0.0600	16.5400	3.9500	2.9440	195.8000
	02465205	3.6290	0.0641	13.5000	4.4200	3.0510	171.4000
	02471026	2.6710	0.0623	22.6400	4.8900	4.7290	186.6000
	02479583	3.6900	0.0560	17.7500	3.6400	6.3480	356.5000
	03574405	1.5050	0.0496	14.2800	3.2000	1.2770	123.4000
	02589280	1.2070	0.0317	12.9000	3.7900	3.3130	293.3000
GA	02189020	1.0570	0.0702	18.8000	6.2800	6.2940	334.2000
	02189030	0.6300	0.0528	20.1300	6.7600	2.0770	93.7000
	02191270	2.1140	0.1034	15.4500	5.2500	7.4860	362.0000
	02191280	1.7220	0.0804	13.7200	7.7900	1.0750	50.7000
	02191600	1.7660	0.0932	17.2300	5.2300	5.7420	245.9000
	02191750	1.2600	0.0857	18.1600	4.9100	11.1490	525.8999
	02192300	1.3310	0.0991	12.4800	6.1500	0.4460	28.9000
	02192400	1.3160	0.0999	16.8400	5.4800	6.1020	303.0000
	02192420	1.3540	0.1101	16.2600	5.4200	1.6960	105.7000
	02193600	1.5750	0.0966	14.8100	5.6500	2.1330	123.3000
	02201110	0.9230	0.0689	18.1200	4.4300	8.1430	415.1001
	02201160	0.8650	0.0704	16.9400	4.4900	7.6930	364.7000
	02201830	1.1400	0.1014	16.7200	6.9200	6.2060	378.8000
	02202910	0.9880	0.0728	19.1100	4.6500	4.9810	201.1000
	02202950	1.1470	0.0572	16.3000	4.7400	5.3680	270.6000
	02208200	1.4930	0.1037	15.5000	6.8600	1.6810	121.0000
	02211459	1.7670	0.0949	14.7700	6.9300	2.4900	159.8000
	02215280	1.4840	0.0669	11.6800	5.6600	4.9360	205.0000
	02216610	0.9600	0.0874	19.4800	5.1300	5.5240	264.7000
	02217250	1.5260	0.0847	16.6900	7.5900	1.3270	61.7000
	02217400	2.0900	0.1085	16.5800	6.1200	2.8920	166.5000
	02217660	1.5850	0.0892	17.4700	6.5000	2.5130	122 000

Table D.10 , continued

'SOUTH' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02218100	1.2440	0.0718	15.8500	5.4800	3.0340	177.2000
02223700	1.3910	0.0774	15.2700	5.5800	4.6870	188.8000
02224200	1.2520	0.0645	11.2000	5.4000	11.8100	523.7000
02225330	1.2970	0.0823	18.9400	4.7400	10.2080	425.3000
02315980	1.2040	0.0607	13.9700	4.8400	4.2260	187.3000
02316220	1.4470	0.0682	10.6400	5.4600	3.8580	222.2000
02316260	0.6460	0.0393	11.9000	5.2700	26.8290	673.7000
02317710	1.0490	0.0620	13.1400	5.0100	4.3640	189.4000
02317760	1.0680	0.0724	19.9200	4.4300	11.0960	490.5000
02317765	1.1000	0.0793	19.7700	4.6400	3.4910	178.6000
02317770	1.1070	0.0625	19.9500	4.4700	7.7840	404.3000
02317775	1.1050	0.0777	19.9000	4.5700	4.4460	181.1000
02317780	1.0280	0.0745	19.6000	4.5000	2.0600	130.1000
02317795	1.3430	0.0730	16.7100	4.9200	7.5830	348.5000
02317845	1.2330	0.0616	19.1700	4.1900	5.0260	213.5000
02317905	1.2690	0.0700	16.1300	4.7500	5.6370	317.0000
02317910	1.6120	0.0626	11.9500	5.1300	3.2580	223.2000
02318015	1.4970	0.0694	13.4900	5.5600	3.5050	181.2000
02318020	1.3330	0.0503	11.2000	6.2600	2.1440	85.1000
02327350	1.4980	0.0729	18.5600	4.7600	4.6970	228.5000
02327400	1.1980	0.0706	21.3500	4.0100	8.9990	375.1001
02346193	2.0320	0.0948	17.8200	5.1900	5.8300	232.1000
02346210	2.1390	0.1011	17.1000	5.2800	6.1360	281.6001
02346217	1.9300	0.0991	17.0200	5.2700	3.3380	177.3000
02350520	1.0980	0.0791	16.2000	4.1700	4.3560	291.3999
02381100	2.4290	0.0623	10.7100	6.4900	1.8130	114.2000
02381600	2.0150	0.0990	12.6300	6.0100	3.1480	216.3000
02381900	2.1290	0.0802	11.5200	6.1700	2.0960	148.4000
02382800	1.6370	0.0471	14.1400	3.8400	2.4560	130.1000
02382900	2.1960	0.0628	10.8100	5.4700	4.9480	303.5000
02383000	1.3680	0.0483	11.8300	4.9400	4.4010	211.3000
02387300	1.2740	0.0430	10.9200	5.0400	0.7960	43.1000
02387560	2.0790	0.0428	10.6800	4.9300	3.1740	175.4000
02387700	1.8290	0.0806	10.7500	5.8300	3.4360	244.3000
02387800	1.5020	0.0568	17.4900	3.3300	4.0260	205.4000
02388200	1.7970	0.0570	14.1900	4.3400	4.1940	202.2000
02388400	1.7110	0.0590	14.5100	4.5100	2.3610	155.3000
02397750	2.4010	0.0494	26.4900	2.8900	4.8180	255.0000
02566660	1.7710	0.0617	17.0800	3.7500	5.5720	259.8999
02566687	1.4110	0.0543	18.8100	3.5100	4.2660	197.2000
MISS 02425980	2.2110	0.0709	10.5500	5.1900	2.0480	152.8000
02435300	1.6250	0.0237	6.0100	5.2600	0.4950	40.4000
02435400	1.7300	0.0677	12.7600	4.8700	1.1740	95.5000
02437550	2.2760	0.0509	14.4200	5.5600	1.4690	86.1000
02440020	2.3040	0.0049	6.7500	3.6500	0.6420	102.7000
02441220	1.5910	0.0080	6.6400	4.6100	1.4060	100.6000

Table D.10 , continued

'SOUTH' Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02447340	1.9730	0.0247	9.4800	4.4900	1.6630	111.4000
02475220	3.1620	0.0501	10.5700	6.1000	0.8380	49.5000
02477090	1.0200	0.0126	8.4200	3.9100	0.9120	67.5000
02477090	1.0200	0.0126	8.4200	3.9100	0.9120	67.5000
02478600	3.9380	0.0439	10.9000	4.3600	1.8960	99.5000
02479165	3.5440	0.0473	12.6200	4.5100	0.7840	60.9000
02481505	2.5510	0.0564	15.3400	4.7200	3.5090	200.2000
02485780	1.7060	0.0247	9.6800	3.8400	1.0350	89.4000
02485900	2.6960	0.0306	9.3800	5.0800	2.9760	115.8000
02485900	2.6960	0.0306	9.3800	5.0800	2.9760	115.8000
02487670	3.3770	0.0594	14.6200	4.6700	1.8820	98.5000
02487710	3.0610	0.0622	17.4500	4.2900	1.7320	120.9000
02488550	3.6880	0.0614	15.2500	4.4200	1.1570	63.2000
02488680	2.7290	0.0461	10.6800	6.5400	1.0820	61.4000
02489030	3.8340	0.0544	14.0300	4.5400	1.7640	100.7000
02489160	3.1470	0.0466	12.2500	4.4700	1.5520	113.6000
07029252	1.1080	0.0663	13.7800	5.1300	1.4060	123.8000
07267200	1.9590	0.0282	6.6100	5.3500	0.8140	56.1000
07277550	1.2020	0.0376	10.1900	4.8400	0.6030	55.4000
07282300	1.2570	0.0293	10.5800	3.9200	1.9680	108.8000
07285700	1.8990	0.0389	13.6900	4.8200	3.0190	142.0000
07287140	0.5940	0.0123	9.1700	5.2600	1.3280	87.4000
07287520	2.0980	0.0430	15.1400	4.7800	2.1410	150.1000
07287520	2.0980	0.0430	15.1400	4.7800	2.1410	150.1000
07288568	2.3010	0.0025	6.9200	4.0800	0.6080	55.2000
07289640	1.7740	0.0255	9.5700	4.4500	0.6420	60.8000
07289640	1.7740	0.0255	9.5700	4.4500	0.6420	60.8000
07290220	2.0380	0.0429	13.9100	5.8100	0.9570	51.5000
07290525	2.1330	0.0295	9.6400	4.2700	2.0530	143.6000
07290910	2.6080	0.0373	15.8600	4.0500	1.9220	196.2000
07294400	4.6710	0.0400	13.9700	5.1200	0.9860	50.0000
07294400	4.6710	0.0400	13.9700	5.1200	0.9860	50.0000
07373550	2.4490	0.0284	15.6600	3.8500	0.9020	61.6000
07375235	2.9840	0.0340	10.8500	4.4200	3.0600	197.5000
07376665	3.3430	0.0302	11.5500	4.6400	1.1890	83.6000
07376665	3.3430	0.0302	11.5500	4.6400	1.1890	83.6000
07376760	2.0160	0.0265	10.4100	4.1800	2.9520	136.1000

Table D.10 , continued

Using Equations from 'NORTH' Sample for Sites in Study in 'NORTH' Region

	Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
ILL	03338100	2.0400	0.0995	16.8500	2.0400	2.5150	95.7000
	03344250	1.4040	0.0539	17.7100	1.9000	0.9130	58.7000
	03380300	2.0840	0.0336	15.1400	1.4900	0.2460	35.8000
	03380450	1.5410	0.0417	16.6100	2.3600	0.3350	58.8000
	03381600	2.3420	0.0606	17.7600	2.1200	0.3260	45.6000
	03382025	2.2090	0.0439	16.2100	2.6800	0.5050	59.3000
	05418800	3.2970	0.0598	15.9600	4.9200	0.3760	47.9000
	05437600	1.4600	0.0883	15.6000	2.8400	1.3530	76.0000
	05438850	1.5900	0.0900	17.9800	3.0500	1.5730	75.5000
	05439550	1.8750	0.0835	16.1600	2.9400	1.0450	70.2000
	05448050	2.3100	0.0765	16.3600	4.8100	0.3830	42.6000
	05469750	2.1300	0.0852	17.5200	3.3700	0.5230	70.3000
	05495200	1.6790	0.0700	18.2200	3.5100	0.7740	92.3000
	05502120	2.7180	0.0551	17.5800	3.2700	0.5440	56.8000
	05527050	1.5690	0.0537	13.0500	1.5000	0.9900	84.2000
	05536265	0.2420	0.0941	17.5600	2.6200	11.3930	115.2000
	05541750	1.4140	0.1088	13.9100	2.2100	4.2100	153.4000
	05551800	3.2310	0.0615	14.2800	4.0600	0.3600	52.9000
	05554600	1.7320	0.0468	15.6700	1.9300	0.4400	40.6000
	05555400	2.9270	0.0706	16.7600	3.3100	0.4820	42.1000
	05557100	2.7230	0.0737	15.2200	6.1900	0.3400	46.6000
	05558050	3.8010	0.0548	8.3600	3.7800	0.0840	21.9000
	05558075	3.3380	0.0692	15.0300	3.9800	0.2560	34.3000
	05566000	1.3140	0.0936	17.9600	2.7800	4.4130	114.9000
	05572100	2.6670	0.0875	15.4400	2.3500	0.6860	35.1000
	05577520	2.5530	0.0818	15.3200	2.8500	1.7590	79.0000
	05577700	2.4080	0.0688	16.9100	2.8600	0.9550	67.7000
	05586500	1.4630	0.0685	16.9400	3.0700	1.6250	100.3000
	05587850	1.6300	0.0479	19.4600	2.7200	0.6300	64.8000
	05591500	0.9580	0.0872	15.9400	1.9400	9.7250	141.4000
	05594200	1.6380	0.0532	17.8400	2.7400	1.5460	112.8000
	05595550	2.2970	0.0563	19.1400	2.4900	0.5790	68.1000
	05596100	1.7060	0.0395	17.2400	1.9600	0.8270	80.9000
	05599640	1.7710	0.0438	22.6900	2.1200	0.3810	54.7000
MO	05497700	1.0440	0.0452	12.9200	3.4600	1.1730	78.7000
	05502700	1.4660	0.0406	12.6900	2.8500	0.5420	57.8000
	05503000	0.5920	0.0350	14.1600	2.6100	1.7150	83.2000
	06815550	2.3370	0.0656	17.3500	4.3100	0.5020	52.0000
	06816000	1.7880	0.0600	14.9600	5.0500	1.4450	92.0000
	06820000	0.8900	0.0639	13.6600	4.7700	2.5980	123.4000
	06897700	3.0310	0.0494	9.3600	3.3500	0.4220	58.7000
	06902500	0.8180	0.0545	12.1100	4.5300	1.6600	102.0000
	06902800	1.2000	0.0623	5.7200	4.7400	0.9060	63.1000
	06907200	1.6280	0.0381	6.7600	4.8200	1.1570	61.3000
	06908300	2.1280	0.0531	17.5200	2.9500	0.7070	60.2000
	06909700	2.8340	0.0551	7.2200	7.2400	0.5160	50.5000
	06910250	2.1610	0.0396	19.4800	2.0800	0.3870	44.1000
	06918700	1.3730	0.0339	10.8400	2.6300	0.6820	66.9000
	06919200	1.7420	0.0587	13.4700	2.2800	0.2450	28.3000
	06921740	1.7740	0.0456	17.9900	3.2100	0.6690	44.8000

Table D.10 , continued

'NORTH' Equations

Site ID	PSP	KSAT	RGP	BMSM	KSW	TC
06925300	2.8220	0.0459	2.9300	2.7400	0.7930	56.9000
06927100	1.6240	0.0383	12.4100	3.6600	0.5870	47.5000
06931500	1.5580	0.0303	23.8700	1.6400	1.4350	88.1000
06935800	2.7860	0.0404	12.3100	3.6300	0.6430	51.8000
07011200	2.1690	0.0498	7.1000	2.7100	0.5360	56.4000
07011500	4.2230	0.0574	14.7200	4.1600	0.7480	43.9000
07015500	3.7170	0.0534	18.2000	2.0300	0.6760	51.8000
07017500	1.6360	0.0418	11.5600	2.2800	1.1020	103.4000
07064300	1.6780	0.0521	8.8800	2.5900	0.6880	84.0000
07064500	1.3620	0.0489	4.9500	3.9400	1.4460	108.2000
07185500	1.5520	0.0483	9.9300	3.5800	1.3580	94.5000

Table D.10 , continued

Using Equations from 'GEORGIA' Sample for Sites in Georgia

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02189020	1.0100	0.1038	16.1900	7.8100	5.1530	324.3999
02189030	0.9930	0.1027	19.7000	7.4400	0.7400	75.8000
02191270	1.6930	0.0956	10.8200	6.1100	7.2570	376.0000
02191280	0.9990	0.0878	13.9600	6.8900	0.8050	42.0000
02191600	1.1300	0.0984	13.8000	4.9000	4.5040	205.8000
02191750	1.1810	0.0988	15.6400	4.2500	9.6490	483.3000
02192300	2.1690	0.1126	14.0200	4.1800	0.6290	29.9000
02192400	2.0780	0.1076	13.5400	4.2800	5.3310	293.5000
02192420	2.6830	0.1190	12.2900	4.3400	2.2670	118.4000
02193600	2.6460	0.0945	13.9100	4.4300	1.8520	122.2000
02201110	1.1570	0.0783	18.1000	3.3700	8.3900	455.2000
02201160	1.3310	0.0819	18.1500	3.4900	8.5720	394.1001
02201830	2.3360	0.1163	12.1100	5.9100	5.6670	264.7000
02202510	1.2850	0.0806	18.1900	4.8500	3.9570	200.8000
02202550	0.6700	0.0599	18.5300	4.6900	4.8300	232.2000
02208200	2.3390	0.1125	11.7800	7.2100	1.8710	126.1000
02211459	1.3790	0.0936	12.4600	6.5000	2.7140	174.5000
02215280	1.2340	0.0608	15.7700	4.6500	5.4890	200.1000
02216610	1.5660	0.1068	13.7700	6.7400	8.3290	365.6000
02217250	2.7630	0.1042	15.8200	7.9000	1.0180	52.0000
02217400	1.9730	0.1063	11.8000	7.0900	3.5040	174.8000
02217660	2.4460	0.1015	14.9100	8.2100	2.4350	121.1000
02218100	1.0300	0.0760	16.6800	4.9200	3.0510	193.7000
02223700	1.3820	0.0772	16.4300	4.3900	3.7590	165.6000
02224200	1.1630	0.0592	15.9700	4.8800	12.7490	548.8000
02225330	1.2040	0.0894	17.1100	4.7300	8.7220	400.2000
02315980	1.0070	0.0582	17.2100	4.7600	5.2430	212.6000
02316220	1.2460	0.0570	14.4300	5.8900	4.4090	279.3000
02316260	0.8400	0.0341	15.8000	7.1400	23.7570	648.8000
02317710	1.1290	0.0589	15.5900	6.3900	6.9340	233.9000
02317760	1.0010	0.0821	18.7200	4.4600	10.6470	503.8999
02317765	1.2210	0.0911	17.6000	4.5600	3.3780	195.1000
02317770	1.2500	0.0939	17.3700	4.6000	8.7320	455.2000
02317775	1.2010	0.0882	17.8200	4.8200	4.2930	182.8000
02317780	1.1540	0.0855	18.0200	4.7600	2.1780	161.0000
02317795	1.0630	0.0737	16.6400	5.1500	6.4010	354.1001
02317845	0.8020	0.0667	20.6300	4.4600	4.0500	204.7000
02317905	1.0120	0.0701	16.8300	5.5500	6.0160	374.5000
02317910	0.9650	0.0543	16.3500	5.7000	3.1220	279.5000
02318015	1.0010	0.0686	15.2700	6.9500	3.5480	206.5000
02318020	0.7820	0.0495	17.6000	7.3400	1.9430	83.0000
02327350	0.7170	0.0808	16.1200	7.1000	5.6950	261.1001
02327400	0.7960	0.0794	18.9700	6.1400	7.2700	393.1001
02346193	1.3110	0.0974	13.7300	5.0300	3.9800	185.9000
02346210	1.9390	0.1019	12.5800	5.6400	5.5690	257.6001
02346217	2.4490	0.1065	12.4200	5.6800	3.5170	178.6000
02350520	1.4060	0.0814	16.0200	5.3600	11.2350	462.5000
02381100	1.3490	0.0716	11.1300	6.7700	2.1230	187.2000
02381600	1.9960	0.0953	8.1900	7.0600	5.2820	234.5000
02381900	1.4350	0.0708	12.8800	6.7000	2.9120	154.5000

Table D.10 , continued

"GEORGIA" Equations

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02382800	1.7240	0.0399	14.6000	3.4400	2.3690	113.0000
02382900	1.6010	0.0570	9.7800	4.9100	6.0550	312.8999
02383000	1.5860	0.0483	16.0700	3.9300	4.4830	201.6000
02387300	1.0110	0.0453	20.4400	4.3700	0.7580	39.7000
02387560	1.0210	0.0369	16.3800	4.2100	4.1380	183.6000
02387700	1.9500	0.0785	6.0200	6.1600	4.8960	274.6001
02387800	1.6000	0.0631	15.4700	3.1600	5.4330	211.4000
02388200	1.4620	0.0591	13.0900	3.8700	4.7530	189.8000
02388400	1.5010	0.0632	15.9200	4.3600	3.3220	170.6000
02397750	1.2170	0.0385	26.2800	2.8900	6.9300	269.1001
03566660	0.9580	0.0617	16.6000	3.6000	4.1210	246.2000
03566687	1.0730	0.0610	20.1400	3.2300	3.6350	179.9000

Table D.10 , continued

Using Equations from 'ILLINOIS' Sample for Sites in Illinois

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
03338100	2.7480	0.0778	19.6500	2.0500	2.8380	147.4000
03344250	0.7660	0.0464	17.6300	1.4100	1.2820	27.8000
03380300	2.6750	0.0310	15.5900	1.3000	0.1420	33.3000
03380450	0.8530	0.0607	16.6500	1.7900	0.3160	93.1000
03381600	4.1140	0.0925	21.1800	1.9900	0.3140	71.9000
03382025	1.4830	0.0567	16.1700	7.8900	0.5010	114.9000
05418800	2.5120	0.0636	15.2800	3.3500	0.2490	92.3000
05437600	0.5910	0.0583	16.8900	1.6100	1.4890	151.8000
05438650	2.1010	0.0711	19.5000	2.6500	1.6760	118.2000
05439550	0.5780	0.0561	17.5300	1.6600	1.0640	153.6000
05448050	2.7160	0.1865	16.2000	5.6300	0.3460	39.4000
05469750	2.3500	0.0806	19.4600	4.0900	0.5910	65.4000
05495200	1.2220	0.0689	20.0900	2.6800	0.9120	128.8000
05502120	3.3310	0.0435	19.6500	1.7600	0.3130	73.1000
05527050	1.2070	0.0470	12.6100	1.9200	0.9250	134.9000
05536265	0.1510	0.3916	16.4100	2.2400	6.2930	201.5000
05541750	0.8540	0.0944	12.1000	2.4600	3.5790	145.7000
05551800	2.2570	0.0519	15.6900	2.6600	0.2770	66.6000
05554600	2.4500	0.0695	15.7100	2.1300	0.3620	38.3000
05555400	4.7470	0.0969	16.7200	3.8800	0.3640	38.0000
05557100	1.1630	0.1025	12.6800	4.9300	0.3400	75.8000
05558050	3.3250	0.0582	7.7800	3.1200	0.0560	15.1000
05558075	4.3390	0.0623	17.5500	3.3200	0.2280	45.0000
05566000	1.1510	0.0819	19.1600	3.2700	4.3890	150.2000
05572100	4.3060	0.1042	16.0900	2.5300	0.3590	15.3000
05577520	4.3280	0.1251	14.8600	3.5500	1.0490	57.0000
05577700	3.4680	0.1027	16.6300	3.1900	0.7720	71.0000
05586500	1.2250	0.0780	17.8400	2.3600	1.2870	156.1000
05587850	1.3680	0.0653	20.5600	2.3400	0.7680	93.3000
05591500	0.5610	0.0777	16.1000	2.0300	10.3950	191.1000
05594200	1.1040	0.0620	17.4900	2.0000	1.8260	155.0000
05595550	7.5110	0.1381	22.5500	2.6900	0.5140	127.0000
05596100	1.4440	0.0436	17.3600	1.3800	0.7620	118.2000
05599640	0.9640	0.0336	27.5300	1.5400	0.4020	148.6000

Table D.10 , continued

Using Equations from 'MISS' Sample for Sites in Mississippi

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
02429980	4.3950	0.0596	12.7700	4.7000	1.3610	178.9000
02435300	1.2470	0.0266	2.9900	5.6200	0.5020	43.6000
02435400	3.7310	0.0495	14.7500	4.9200	0.8930	100.4000
02437550	2.8380	0.0345	19.7000	6.3300	1.5550	83.3000
02440020	0.3760	0.0082	5.5900	3.7600	0.5280	68.7000
02441220	0.4300	0.0107	4.6000	3.8000	1.5560	93.1000
02447340	2.0840	0.0248	7.3200	4.6400	1.5710	109.1000
02475220	3.5920	0.0499	8.8900	5.4200	0.8660	61.3000
02477090	0.8750	0.0167	8.5800	5.2900	0.8950	50.2000
02477090	0.8750	0.0167	8.5800	5.2900	0.8950	50.2000
02478600	4.9870	0.0631	18.0000	4.9600	1.7160	143.1000
02479165	4.3060	0.0519	14.2400	3.9000	0.8540	43.1000
02481505	4.3880	0.0663	11.1500	2.9300	3.0980	159.5000
02485780	2.0420	0.0255	7.9700	3.3700	0.9010	101.6000
02485900	3.0430	0.0372	7.5700	5.2100	2.7860	203.0000
02485900	3.0430	0.0372	7.5700	5.2100	2.7860	203.0000
02487670	4.9260	0.0522	21.6700	3.5100	1.7290	118.5000
02487710	4.9440	0.0524	29.0900	4.0000	1.4440	137.1000
02488550	5.1690	0.0584	23.7800	3.6600	1.1660	76.5000
02488680	4.5740	0.0502	6.1200	4.9700	1.1320	88.8000
02489030	5.2220	0.0592	21.3900	4.6300	1.5550	120.2000
02489160	4.4010	0.0507	17.1500	4.0700	1.3330	101.5000
07029252	1.8440	0.0388	8.7200	4.6500	0.9880	113.0000
07267200	1.7750	0.0308	4.1600	6.6200	0.8640	50.4000
07277550	1.7560	0.0256	6.4500	3.6100	0.6380	38.2000
07282300	1.7660	0.0241	9.0200	4.4200	2.2200	88.8000
07285700	1.9760	0.0275	12.7300	5.3200	2.7090	171.6000
07287140	1.1080	0.0080	8.1000	4.9000	1.8220	105.4000
07287520	1.7170	0.0311	16.1400	3.2300	1.8330	119.2000
07287520	1.7170	0.0311	16.1400	3.2300	1.8330	119.2000
07288568	0.5510	0.0032	5.1600	5.7600	0.6100	96.2000
07289640	2.2670	0.0244	6.6000	4.7200	0.6710	58.8000
07289640	2.2670	0.0244	6.6000	4.7200	0.6710	58.8000
07290220	2.7470	0.0360	10.1600	5.1300	1.0610	87.6000
07290525	2.3770	0.0338	6.5100	4.5300	1.5590	171.8000
07290910	1.9870	0.0342	16.4500	4.1000	1.2110	205.2000
07294400	3.8400	0.0430	12.1000	7.4700	1.2210	52.4000
07294400	3.8400	0.0430	12.1000	7.4700	1.2210	52.4000
07373550	2.2540	0.0226	16.0300	5.8800	1.0260	74.2000
07375235	2.9770	0.0407	12.1000	4.3900	2.5250	175.5000
07376665	3.2120	0.0342	13.9000	7.2000	1.3300	75.8000
07376665	3.2120	0.0342	13.9000	7.2000	1.3300	75.8000
07376760	2.3920	0.0322	7.2300	5.4200	3.4980	118.6000

Table D.10 , continued

Using Equations from 'TENN' Sample for Sites in Tennessee

Site ID	PSP	KSAT	RGF	BMSM	KSW	TC
03313600	5.5760	0.0828	15.9800	3.9600	0.6650	75.6000
03313620	3.6540	0.0867	15.7200	4.0600	1.2840	134.6000
03418900	3.9690	0.0739	9.5300	3.3400	1.5030	106.5000
03420360	1.1810	0.0445	15.5500	3.9600	2.1460	201.6000
03420380	2.1770	0.0343	13.2900	3.6400	1.8570	183.1000
03420400	2.2680	0.0526	15.3500	3.6700	1.6800	248.1000
03430400	2.8970	0.0298	7.6300	1.8900	1.3330	214.7000
03431520	6.9330	0.1119	14.4900	3.7400	0.7780	97.2000
03431580	3.0190	0.0604	9.5700	2.9400	0.7840	153.0000
03431600	1.5490	0.0926	12.9000	3.6700	1.3420	197.1000
03431650	7.3110	0.0570	8.4000	2.6500	0.3680	59.6000
03435020	2.3460	0.0921	15.6600	3.9900	0.7140	134.3000
03435030	1.7360	0.0925	15.6600	4.0200	0.5680	117.7000
03435600	1.6780	0.0690	18.3200	4.8000	1.2810	138.2000
03461200	4.2280	0.0820	11.5900	3.0700	5.0370	329.8000
03469110	2.7480	0.0554	13.2100	2.4900	2.4350	116.3000
03486225	7.6130	0.1228	18.1500	5.3300	1.3540	115.0000
03519610	8.8740	0.1196	19.0900	2.3700	0.9990	113.9000
03519630	10.5790	0.1036	18.8900	2.2700	0.9510	115.0000
03519640	2.0330	0.1008	16.2300	2.4200	0.3880	84.0000
03519650	3.7150	0.1044	16.1000	2.3100	0.9380	90.5000
03535140	3.1240	0.0716	11.1800	4.4400	0.6510	56.6000
03535160	1.2460	0.0738	11.5900	4.1600	0.9640	126.1000
03535180	2.4880	0.0841	15.9900	4.5800	2.4200	131.2000
03538900	2.1920	0.0967	12.5500	3.4000	2.7720	207.1000
03539100	3.9820	0.0987	14.7200	3.0500	0.8420	90.2000
03597300	2.8950	0.0592	8.8300	2.8400	1.8800	174.1000
03597300	2.8950	0.0592	8.8300	2.8400	1.8800	174.1000
03597400	2.2160	0.0600	9.0900	2.8100	1.3640	169.1000
03597450	5.8320	0.0824	12.8200	3.0500	0.8420	55.3000
03597450	5.8320	0.0824	12.8200	3.0500	0.8420	55.3000
03597500	1.6870	0.0553	8.9700	2.7500	0.9230	132.8000
03597550	2.5790	0.0337	6.3800	2.5700	1.6150	97.9000
03597550	2.5790	0.0337	6.3800	2.5700	1.6150	97.9000
03604070	15.6840	0.0839	20.4200	4.2400	0.8740	77.0000
03604080	7.8550	0.0952	19.5700	4.5200	1.3180	102.1000
03604090	6.3690	0.0978	18.7600	4.2700	0.9150	134.9000
03604100	4.9100	0.0955	17.9300	4.2900	1.2590	170.6000
07028935	3.0500	0.0676	16.1400	3.1500	0.2490	42.3000

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VITA

Fred liscum was born in Pampa, Texas on July 23, 1944. In 1962, he graduated from C. E. Byrd High School in Shreveport, Louisiana. He received both the Bachelor of Civil Engineering degree in 1966 and the Master of Science in Civil Engineering degree in 1968 from the Georgia Institute of Technology. Mr. Liscum returned to the Georgia Institute of Technology in 1971 under provisions of the Federal Employees Training Act, and subsequently fulfilled the requirements as a candidate for the degree of Doctor of Philosophy in the School of Civil Engineering.

Mr. Liscum has been employed as a Hydrologist by the U. S. Geological Survey since October, 1967. He has been assigned to positions in Ft. Worth, Texas, Reston, Virginia and Houston, Texas. His assignment in Reston, Virginia was with a research study concerning the U. S. Geological Survey Rainfall-Runoff Model. This opportunity allowed him to complete this dissertation. Currently, he is a project manager for the Houston Urban Runoff Project in Houston, Texas.

Mr. Liscum is a member of the American Society of Civil Engineers and the American Geophysical Union. He is a member of Chi Epsilon, Tau Beta Pi, and Phi Kappa Phi honorary societies, and Lambda Chi Alpha social fraternity.

Mr. Liscum was married in 1966 to the former Miss Sarah Lane Pryor. They have three sons, Dean Patrick, Samuel Edward and Jason Daniel, and one daughter, Jennifer Lane.